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Evaluation of the recreational marron fishery against environmental change and human interaction

Final FRDC Report – Project No. 2003/027

Authors: M. de Graaf, S. Beatty and B.M. Molony
Editors: D. Baxter and R. Larsen

Government of **Western Australia**
Department of **Fisheries**

Australian Government
Fisheries Research and Development Corporation

Western Australian Fisheries and Marine Research Laboratories

Fish for the future

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Fisheries Research Division
Western Australian Fisheries and Marine Research Laboratories
PO Box 20 NORTH BEACH, Western Australia 6920

Australian Government
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Enquiries:

WA Fisheries and Marine Research Laboratories, PO Box 20, North Beach, WA 6920
Tel: +61 8 9203 0111
Email: library@fish.wa.gov.au
Website: www.fish.wa.gov.au
ABN: 55 689 794 771

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Contents

Non-technical summary **1**

Acknowledgements **4**

Background **5**

Need **7**

Objectives **8**

1.0 Changes in the distribution of marron in southwestern Australia **9**

1.1 Introduction 9

1.2 Methods 9

1.3 Results 10

1.4 Discussion 11

1.5 References 15

2.0 Evaluation of relative gear efficiency and standardisation of long-term catch per unit effort from a recreational crayfish fishery for marron (*Cherax cainii*) in southwestern Australia **22**

2.1 Introduction 22

2.2 Methods 23

2.3 Results 26

2.4 Discussion 28

2.5 References 33

3.0 Assessing the influence of key environmental variables on the fishery performance of the recreational crayfish fishery for marron (*Cherax cainii*) in southwestern Australia **42**

3.1 Introduction 42

3.2 Methods 43

3.3 Results 45

3.4 Discussion 46

3.5 Management implications 48

3.6 References 49

3.7 Appendices 66

4.0 Identifying and ranking the impacts of sources of mortality of marron in southwestern Australia **70**

4.1 Introduction 70

4.2 Materials and Methods 70

4.3 Results 71

4.4 Discussion 73

4.5 Ranking mortality, interspecific predation and marron population bottlenecks ... 77

4.6 References ... 79
4.7 Tables ... 81
4.8 Figures ... 85

5.0 Population biology of indicator marron stocks and implications for the sustainable management of the fishery ... 94
5.1 Introduction ... 94
5.2 Methodology ... 94
5.3 Results ... 99
5.4 Discussion ... 101
5.5 References ... 107

6.0 Spatial and temporal variation in reproductive characteristics of marron, *Cherax cainii* (Crustacea: Decapoda), in southwestern Australia ... 125
6.1 Introduction ... 125
6.2 Materials and Methods ... 125
6.3 Results ... 126
6.4 Discussion ... 127
6.5 References ... 131

7.0 Estimating marron (*Cherax cainii*) densities in rivers and dams: influence of sampling method, habitat and vertical distribution ... 139
7.1 Introduction ... 139
7.2 Materials and Methods ... 139
7.3 Results ... 141
7.4 Discussion ... 143
Index of abundance ... 145
7.5 References ... 146

8.0 Estimating abundance of juvenile marron, *Cherax cainii*, in dams and rivers in southwestern Australia ... 159
8.1 Introduction ... 159
8.2 Materials and Methods ... 159
8.3 Results and Discussion ... 160
8.4 References ... 163

9.0 Benefits and Adoption ... 169

10.0 Further developments ... 170

11.0 Planned outcomes ... 171

12.0 Conclusions and Recommendations ... 175

13.0 Appendices ... 179

Non-technical summary

The distribution of marron in the southwest of Australia has seen many changes since European settlement. Reconstructions of their range from historical records suggested that marron inhabited the waters between the Harvey River and Denmark River. Due to translocation, their range has expanded as far north as the Hutt River and as far east as Esperance. Although at present marron still exist in all the original rivers within the southwest, their distribution within these rivers has contracted. Poor water quality, salinity, low rainfall and environmental degradation in the upper and lower reaches have restricted marron populations.

Historically, management decisions in the Recreational Marron Fishery have been based on fishery-dependent CPUE data collected using a logbook survey and phone survey. A critical assumption has been that the fisheries-dependent CPUE values were proportional to abundance. However, raw or nominal fisheries-dependent CPUE effort data are seldom proportional to abundance and relative abundances indices based on nominal and even standardised CPUE data are notoriously problematic and often provide little useful guidance for management. Although, the fishery-dependent programs provide high quality data on changes in the fishery, in isolation, these data provided limited information on the effects of fishing and the impact of fishery regulations on marron abundance. Standardising the fishery-dependent CPUE data for just one (introduction of snare-only areas during the 1990s) of the numerous management changes illustrated the significant bias in raw, nominal CPUE data. The use of biased fishery-dependent data as measures for Recreational Marron Fishery productivity was probably one of the contributing factors limiting the success of developing predictive models using non-fishery variables (e.g. rainfall, river flow).

After a thorough review of (historical) sampling methods, a new fishery-independent annual research program using inexpensive box traps was implemented in 2006. Trapping allowed technical staff to sample several sites (2-4) simultaneously instead of just one site per night. More importantly, traps were set late afternoon and retrieved the following morning, removing the serious occupational health and safety issues associated with the historical late night (18:00-1:00) sampling trips using drop nets and scoop nets. Furthermore, trapping removed the high level of subjectivity (e.g. operator skill level) associated with the traditional methods, especially scoop netting. Trap data appeared to be the most suitable as an index of relative abundance of marron. Interestingly, comparing trap catches with density data obtained through visual surveys using scuba revealed that at least over soft substrate in dams, trap catches can be used as both a measure of relative and absolute (#/m^2) abundance.

There were large differences in the fishing mortality and rates of exploitation of the two key indicator stocks, Wellington Dam and the Warren River. Fishing mortality and subsequent rates of exploitation were much greater in the habitat poor dam stock relative to the relatively pristine river stock. This was attributable to the differences in habitat and food availability between these systems. Marron are also susceptible to teleost fish predation during the juvenile part of their life history. For example, small (<30 mm Orbital-Carapace Length, OCL), juvenile marron were preyed upon by feral/introduced fish like redfin perch and trout and native predators such as, freshwater catfish, aquatic birds, longneck turtles and water rats. However, the current study did not find native predators to have a significant impact on marron recruitment to the fishery. Among the feral/introduced predatory fish, redfin perch (>20 cm Standard Length, SL) consumed by far the most marron throughout the year. Small trout feed predominantly on insects with larger individuals (>30cm SL) shifting towards fish and crayfish, including marron. The highest marron densities were found in water bodies with

complex hide habitat despite large numbers of introduced predatory fish like redfin perch, rainbow and brown trout; highlighting the importance of complex habitat in reducing intra and interspecific predation and maintaining recruitment to the fishery. As such, no evidence was found to support the hypothesis that marron stocks are significantly (recruitment) limited due to predation in systems with complex habitat.

The Recreational Marron Fishery has targeted (adult) marron since the introduction of a minimum legal size of 57 mm OCL in 1952. The reduction of the fishing season from 135 days (~500,000 marron) in the 1970s and 1980s, to 16 days (~50,000 marron) in the early 2000s, has significantly reduced the impact of fishing mortality.

Marron densities and population structure were strongly influenced by habitat type. Both trapping and visual surveys using scuba, clearly demonstrated that complex habitat sustained higher densities of marron over a wide size range, while fewer, but mainly larger marron, occurred over soft, flat substrate.

The key indicator populations studied in the Warren River and Wellington Dam had the highest densities of marron of all the surveyed water bodies but the population dynamics in each dam were strikingly different. In both water bodies, juveniles initially grow at roughly the same rate but the population in Wellington Dam is stunted, very few animals larger than 60 mm OCL. While in the Warren River animals between 60-90 mm OCL were common and continued to grow, tagging data showed that in Wellington Dam adult marron would moult but not increase in size. The study demonstrated that the Wellington Dam stock was effectively fully exploited and had very low productivity. By contrast, the Warren River stock had relatively low fishing exploitation and a high productivity driven by higher growth rates of trappable individuals coupled with higher densities. The differences in densities and growth of larger individuals were attributed to differences in habitat quality and food resources. The differences in exploitation rates were attributed to the greater fisher accessibility in the dam relative to the river. These differences are likely to be similar in other dam and river stocks (with the exception of Harvey Dam) and thus have direct implications for the management of the two sectors of the fishery.

A key finding of the study is that water quality (salinity) and the quality and availability of complex habitat (intact riparian vegetation providing woody debris in rivers and a lack of complex habitat in dams) are the critical bottlenecks restricting marron distribution and abundance in the southwest of WA.

Little temporal and spatial variation was observed in both ovarian (potential) and pleopodal (effective) fecundity among a dozen marron populations. Size-at-maturity showed little temporal but considerable spatial variation ranging from 30-70 mm OCL. Preliminary results indicated that at present the minimum legal size in the Margaret, Blackwood and Moore Rivers might be insufficient to protect the female breeding stock. Furthermore, it appeared that in some populations (e.g. Shannon River), females were not reproductively active every year and may trade-off growth for reproduction. Alternating between growth and reproduction has been demonstrated for Tasmanian and Victorian freshwater crayfish populations where low water temperatures restrict the growing/breeding season.

Limited information is available on the early phases of juvenile marron in the field. Visual surveys demonstrated that in dams juvenile abundance is highly correlated with the presence of complex, hard substrate. Several designs of 'habitat traps' were successfully tested in Wellington Dam and Warren River to capture juvenile marron.

However, the design of the ‘habitat trap’ will need some further adjustment and testing, before this method can be used as a reliable recruitment abundance index.

Tagging juvenile marron with small (<1mm), internal coded micro wire tags was highly successful and proved to be a potentially powerful tool to study juvenile biology in the field. Laboratory experiments showed that tagging had no effect on mortality or growth of small juvenile marron and tag retention was high.

The degradation (salinisation, reduced surface and groundwater inflow) of the rivers in the southwest is a threat to both the recreational marron fisheries and the marron populations upon which it is based and has resulted in reduction of the inland range of the species. The exclusion of recreational fishing from public dams (e.g. Stirling Dam and possible Logue Brook Dam and Wellington Dam in the near future) reduces the size of the marron fishery but simultaneously creates unofficial protected areas for marron and other native aquatic fauna.

The major threat to the ongoing sustainability of the fishery is the decline in the health of the freshwater systems in which it currently occurs. As such, a key recommendation is to promote inter-agency cooperation in addressing the decline of river health; particularly with regard to water quality and riparian vegetation.

The future of the recreational marron fishery lies in also promoting it as a skilful, exciting, inexpensive and fun outdoor activity that can be enjoyed by the whole family.

As such, creation of a snare-only, ‘Trophy’ marron fishery with conservative bag and possession limits throughout the whole fishery would greatly simplify research, compliance and management. More importantly, such an approach would allow for a considerable increase in season length that will allow more people to participate or organise multiple trips, enhancing visitation to the southwest region and further contributing to regional economies.

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Background

The Recreational Marron Fishery is an iconic and important licenced recreational fishery in Western Australia.

Over 30 years of fishery-dependent data collected on the recreational marron fishery by the Department of Fisheries (DoF) indicates a significant decline in the production of this important licensed recreational fishery.

Marron populations are vulnerable to fishing pressure and predation from exotic fishes as they typically mature as two year olds, breed only once per year and, have a low fecundity and have low dispersal rates.

A critical factor is the overall reduction in the range of marron through time believed to be due to environmental factors (e.g. declining rainfall in the southwest) and non-fishery management practices (e.g. clearing of land in the upper catchments of rivers leading to salinisation of waterways beyond the tolerance level of marron). It is essential that the shrinkage of the recreational marron fishery in the past 25 years be quantified to allow both a reassessment of the declining catches and CPUE, and to estimate the current size of the recreational marron fishery (e.g. total fishable river length, total fishable dam perimeter).

The Recreational Marron Fishery is divided into two broad fishing categories, rivers and dams, and a single river or a single dam is a logical management unit. Approximately 60% of river fishing effort is focused on four rivers, the Warren, Blackwood, Collie and Murray and 85% of dam fishing effort is focused on four dams Wellington, Harvey, Big Brook and Waroona. Thus, although the Recreational Marron Fishery operates over a wide spatial area, there are few key fishing areas.

Historical data sets exist that are mainly fishery-dependent (voluntary logbook holders, annual telephone survey) but there are also some fishery-independent data (Department of Fisheries research surveys and Murdoch University research projects and data from catchment groups (Blackwood Basin Group)). There is a need to critically re-evaluate and model these existing data to develop new performance measures for marron stocks, which would add value to the historical fishery time-series data.

Future management of the recreational marron fishery requires rapid assessment of the fishery and a major component of this project will be to fully determine key population biology parameters in ‘typical’ systems: the Warren River and Wellington Dam. These two sites account for much of the annual fishing effort, historical (fishery-dependent) data is available for these sites and detailed data collection and modelling of existing and new critical information can be carried out. Intensive studies of these two indicator populations would require the growth, mortality and productivity to be quantified which would provide critical biological information to better manage the entire Recreational Marron Fishery. Although detailed information about the productivity of marron stocks (e.g. fecundity, survival to recruitment, growth rate, mortality agents) in these two sites will be assessed, the information will be applicable to other sites within the recreational marron fishery, providing a generic capacity for evaluating the entire fishery.

Changes in legal gears in the recreational marron fishery have occurred for over 50 years and the different legal gears (drop-nets, scoop-nets and snares) are perceived to have different efficiencies. This efficiency will be formally assessed in the current project via an experimental gear comparison trial within the two indicator sites. The efficiencies will be used to re-evaluate historical catch and effort information that exists for the Recreational Marron Fishery in order to assess the impact of gear changes on historical catch and catch-per-unit effort data (CPUE).

Predators (especially exotic redfin perch) have been documented as imposing a high level of mortality on marron, especially during the critical period of juvenile release. However, the relative impacts of natural mortality vectors in relation to fishing mortality have not been assessed. This project will identify and rank sources of marron mortality within the two indicator sites, allowing management to focus on strategies to prioritise control effort on the sources of marron mortality.

Data from other management agencies will be collected, analysed and modelled in relation to recreational marron fishery data to provide insights into the impact of non-fishery variables on the productivity of the recreational marron fishery (e.g. rainfall data maintained by the Bureau of Meteorology; river-flow data maintained by the Waters & Rivers Commission; catchment generation estimates and dam volumes maintained by the Water Corporation and water quality data collected by the Department of Water).

Modelling of the historical environmental data with the historical fishery data will assist DoF fishery managers to identify variables within other management portfolios that significantly affect the productivity of the Recreational Marron Fishery and river health in general. This will enable DoF to influence the practices of other management agencies, so as to increase the productivity and sustainability of the recreational marron fishery.

This project involves a range of different research topics and has therefore been presented as a series of chapters, each dealing with a particular research aspect:

Chapter 1 Changes in the distribution of marron in southwestern Australia.

Chapter 2 Evaluation of relative gear efficiency and standardisation of long-term catch per unit effort from a recreational crayfish fishery for marron (*Cherax cainii*) in southwestern Australia.

Chapter 3 Assessing the influence of key environmental variables on the fishery performance of the recreational crayfish fishery for marron (*Cherax cainii*) in southwestern Australia.

Chapter 4 Identifying and ranking the impacts of sources of mortality of marron.

Chapter 5 Population biology of indicator marron stocks and implications for the sustainable management of the fishery.

Chapter 6 Spatial and temporal variation in reproductive characteristics of marron, *Cherax cainii* (Crustacea: Decapoda), in southwestern Australia.

Chapter 7 Estimating marron densities in rivers and dams: influence of sampling method, habitat and vertical distribution.

Chapter 8 Estimating abundance of juvenile marron, *Cherax cainii*, in dams and rivers in southwestern Australia.

Need

Both the catch and range of marron have reduced over the last 25 years. A re-evaluation of the range will provide both the current extent and future potential of the Recreational Marron Fishery and allow a re-interpretation of current production of the Recreational Marron Fishery.

Selecting two indicator sites will allow mangers to focus research efforts in order to achieve a new, level of detail on growth, production, fecundity, size-at-maturity, recruitment, mortality and survival for indicator stocks as well as develop and improve sampling methodologies. Although focused on indicator stocks, this will produce generic tools applicable to other marron stocks, providing a suite of powerful management indicators.

Changes in legal fishing gears have occurred and the gears are likely to have different efficiencies and may therefore explain a proportion of the decline in marron catches. By quantifying the relative efficiencies of the three legal gears, the historical fishery-dependent data set can be re-evaluated to allocate a proportion of the decline in catches to changes in gears and predictions of the impact of future gear restrictions.

Identifying and ranking the sources of marron mortality, will provide key information on marron survival at various life-stages and allow management to focus resources on controlling important mortality sources.

Environmental variables and management of catchments and water resources profoundly influence the extent and productivity of the entire recreational marron fishery. The collection of data and development of models will allow fishery managers to identify key influences and engage with other management agencies to promote a more sustainable and productive recreational marron fishery.

Objectives

1. Assess the present range of the Recreational Marron Fishery and compare it to the historical range to quantify the reduction in marron range and current extent of the fishery.
2. Assess growth, mortality, fecundity, recruitment and survival of marron in indicator sites to develop performance measures and models of productivity.
3. Quantify the relative efficiency of the three permitted capture methods at indicator sites and use the results to standardise the historical catch and effort database.
4. Pilot the qualitative assessment of mortality sources of a selected marron population.
5. Pilot the identification of the impacts of major environmental variables affecting a selected marron population.

1.0 Changes in the distribution of marron in southwestern Australia

B. Molony, C. Bird, S. Beatty, V. Nguyen and M. de Graaf

1.1 Introduction

Although originally limited to inland waters between the Harvey and Denmark River catchments (Fig. 1) (Morrissy 1978), the translocation of marron in Western Australia increased their range significantly. Morrissy (1978) reconstructed the translocation history of marron in Western Australia through the use of oral history, historical reports and files from the Department of Fisheries, Western Australia (Table 1). From these records Morrissy (1978) described the maximum distribution of marron (Fig. 1). In addition, Morrissy (1978) documented oral records of the contraction of marron from the upper reaches of many rivers in southwestern Australia.

The contraction of the range of marron was reported in the upper reaches of the Blackwood River as early as the 1950s and 1960s (Morrissy 1978). The reduction in upstream distribution in the Blackwood River was estimated at 100 km in 1999 (Taylor and Nickoll 2000), with much of the decline attributed to increasing salinity of upstream reaches as a result of land clearing (Morrissy 1978, Molony et al. 2002) and the subsequent rise in the water table. Clearing of vegetation from inland areas has occurred in other southwestern catchments (Beresford et al. 2001). Thus it is likely that contractions have occurred in the upstream reaches of other rivers within the Recreational Marron Fishery, (e.g. Morgan et al. 2003).

The decline in marron range in southwestern Australia is likely to have impacted on the Recreational Marron Fishery. For example, a reduction in the range of marron is likely to reduce the productivity of the as less marron habitat is available. This is likely to have reduced the total productivity the fishery (as indexed through total catches). Additionally, a reduction in range would also impact on catch rates (marron per fisher per day) as fishers would be forced into a reduced area of marron habitat.

Since the mid 1970s, monitoring of the Recreational Marron Fishery has reported both a reduction in total catches and a reduction in catch rates (see Chapters 2 and 4). How much of the decline in catches and catch rate is attributable to a reduced range of marron in southwestern Australia?

This chapter addresses the issue of range reduction of marron in southwestern Australia. Firstly, the historical range of marron is reconstructed, relying heavily on the information presented by Morrissy (1978). The reduction in the maximum range of marron (as estimated from the details in Morrissy 1978) and data collected in 2003/4 was estimated and used to approximate the reduction in marron range, expressed as a percentage. This allowed the allocation of a proportion of the decline in catches and catch rates in the Recreational Marron Fishery to the reduction in (upstream) marron habitat. Reasons for the decline and management implications of the reduction in range are discussed. Potential issues associated with further reductions in marron range as a result of the estimated impacts of climate change are also discussed.

1.2 Methods

Marron distribution data were collated from three sources:

Published information sources

Previous research data containing information on marron range were reviewed and compiled. Sources included Morrissey (1978), Taylor and Nickol (2001) and Beatty et al. (2005).

Logbook Holders

The Department of Fisheries has managed the collection of data from the Recreational Marron Fishery by a voluntary logbook program for more than 30 years (Molony and Bird 2002). In 2003, 111 logbook holders were asked to identify, on a supplied map, the highest and lowest points where they have captured marron in the last 5 years (1999-2004). In addition, logbook holders were also asked where they had fished in the past five years and not captured marron. This allowed identification of the extent of area where logbook holders fished and captured marron (Fig. 2).

Fisheries Independent Surveys

Fisheries independent surveys (FISs) were undertaken in areas within the Recreational Marron Fishery where data from other sources were limited. Sampling of the lower Blackwood River, Kalgan River, Tone River and upper reaches of the Warren River (Fig. 2) occurred during March and April 2005. This coincided with the late-summer, typically the time of the year where rivers have broken into pools and conditions are most stressful for marron and other aquatic animals. At each location, modified crab drop nets (fitted with 0.5 mm base mesh) were placed along the river at 100 m intervals. The number of drop nets set varied from 6 to 60, according to the length of reach sampled. Drop nets were set one hour before sun-set and retrieved two hours later. GPS coordinates of each net were recorded to allow for further (e.g. water quality) sampling the following day. Marron captured during FIS were measured as being undersized (<55 mm OCL) or legal size (>55 mm OCL) and then released. Water-quality parameters including salinity, temperature and pH were taken at each site on each sampling occasion. (Table 2).

Range compilation

The extant range of marron (2003/04) was estimated based on the three sources of data. The highest upstream and lowest downstream position of marron from recent (post 1995) surveys and information supplied by logbook holders were plotted (Fig 2). If the positions from the three methods varied, the highest and lowest positions were selected.

The extant (2003/4) range of marron was estimated by interpolation among rivers and data sources. When in doubt, a conservative position in each river was estimated, based on the more than 20 years of marron sampling experience by one of the authors (CB).

1.3 Results

Published ranges

The reconstruction of the pre-European range of marron by Morrissy (1978) showed a relatively restricted range. The northern most point was the Harvey catchment with the southeastern extent estimated as the Hay River, west of Albany (Morrissy 1978, Fig. 1). The downstream distribution is likely to be limited by the upstream extent of tidal influence, with the upstream distribution limited by the existence of permanent pools during summer. The post-European distribution of marron includes catchments north of Perth, including the Hutt River (Beatty et al. 2005).

Logbook holders

A total of 47 logbook holders responded with details of their recent marron catches. Most sites of marron catches were relatively low down in many rivers (Fig. 2), although it is likely that logbook holders would fish in areas where they would be more likely to obtain their bag limit. Thus, it was expected that logbook holders would focus effort in the lower reaches of rivers, above the limit of tidal influence.

The maximum inland distribution of marron was clearly defined by some logbook holders in some areas (e.g. upper reaches of the Warren River). In addition, logbook holders reported several rivers where marron were not captured (e.g. Kalgan River), despite being fished in previous years. Most sites in which logbook holders reported no marron were small rivers and tributaries, prone to the effects of salinisation and low rainfall (i.e. prone to ‘drying-up’).

Fishery Independent Surveys

Very few marron were reported from FIS in the four areas examined (Table 3). No marron were recorded from the Kalgan River (Fig. 2), confirming the finding of logbook holders. The presence of estuarine fish species and elevated levels of salinity (Table 3) suggested the system has shifted to being salinised and that marron are extinct from this river.

A small number of under-sized marron were reported from the upper reaches of the Tone sub-catchment of the Warren River (Table 3). Marron were only reported in waters with a salinity of less than 4‰ and were recorded from a similar position as that reported by logbook holders. The downstream distribution of marron in the Blackwood River coincided with the upstream limit of tidal influence, at approximately the position of Warner Glen.

1.4 Discussion

Recent (post 2000) records of marron fishing exist for rivers and dams between the Hutt River (north of Geraldton), to river systems east of Esperance (Morrissy 1978, Molony et al. 2002) (Fig. 1). However, due to land practices, climate change (Molony et al. 2002) and salinisation of upper catchments (Morrissy 1978, Beresford et al. 2001, Morgan et al. 2003), the range of marron has retracted from the upper reaches of many catchments (Morrissy 1978, Taylor 2001).

The distribution of marron has expanded and contracted in response to anthropogenic influences. The expansion of marron range from the pre-European distribution, occurred through legal and illegal translocation and seeding of marron (Morrissy 1978, Molony et al. 2002), resulting in a significant increase in range (Fig. 1). The translocation of marron is likely to have resulted in self-sustaining populations in all waters where marron were able to complete their life-cycle.

The declines in marron distribution from the estimated maximum distribution were also a result of anthropogenic effects, including changes in water quality (Fig. 3), loss of in-stream and riparian habitat (Molony and Bird 2005), broad-scale land-clearing, development of land for agricultural practices and surface-water management (Morrissy 1978, Molony et al. 2002). One result was a rise in the water table in the upper regions of many southwestern catchments, resulting in saline groundwater infiltrating surface waters (Beresford et al. 2001, Morgan et al. 2003). Recreational fishing (overfishing and local depletion) is also likely to have impacted at least on some marron stocks in southwestern Australia.

The reduction in the range of marron from the estimated peak was significant, limiting the range of marron to the middle and lower reaches of the many rivers. Despite the contractions in range within rivers, the current range of marron (2004) is estimated to be greater than the pre-European range due to translocations to the north and east.

The current range is broadly within waterways inside the region identified by the Department of Water as rejuvenated or young drainage (Fig. 4), with the lower river limit to marron distribution defined by the limit of tidal influences. Thus, the current distribution of marron is between the limit of tidal influence (downstream limit) and the influence of saline waters (Fig. 3) (upstream limit). However, the current range of marron is not contiguous through this area. The current continuous range of marron is between the Murray River catchment (south of Perth) to the Hay River (immediately west of Albany). Nonetheless, there are stocks of marron east of Albany, despite marron being absent in the Kalgan River. Similarly, there are isolated stocks of marron north of the Murray River. For example, marron stocks exist in dams and tributaries in the Swan-Coastal catchment (e.g. Mundaring Weir), a short ~20 km section of the Moore River (Fig. 5; de Graaf and Hugh, unpublished data) and in the Hutt River north of Geraldton (Beatty et al. 2005). Additionally, isolated stocks exist in numerous farm dams (e.g. a result of intensive and extensive aquaculture) (Morrissy 1992, Francesconi et al., 1995) and in large irrigation and water supply dams.

The presence or absence of an isolated marron stock outside of the areas limited by the Murray and Hay Rivers, or in upstream reaches, is due to the existence of suitable water quality parameters for marron, likely from the influence of a freshwater spring in the vicinity (Morrissy 1978). From the FIS, marron were only found in waters where salinity was less than 4‰ (Table 3). Morrissy (1978) also identified salinity as limiting marron distribution, but indicated that adult marron could survive salinities at least up to 8‰. However, it is likely that eggs or juveniles have a different, possibly lower, salinity tolerance (Morrissy 1978). This is somewhat supported by the presence of small (i.e. under-size) marron in waters less than 4‰ (Table 3), suggesting that marron may be able to reproduce only in waters with salinities less than 4‰.

Although no doubt exists about the contraction in the range of marron in the Blackwood River system (Morrissy 1978, Nickoll and Horwitz 2000, Taylor and Nickoll 2000) and other river systems (Morrissy 1978, Molony et al. 2002), the results of previous studies suggest that the actual upstream limit to marron in the Blackwood system varies inter-annually. Morrissy (1978) concluded that although the pre-European distribution of marron was well into the upper Blackwood River catchment (at least to the headwaters of the Beaufort River and east of Kojonup, by 1975 the upstream distribution of marron had receded approximately 150 river kilometres. However, Nickoll and Horwitz (2000) surveyed similar sites to Morrissy (1978) in 1996 and concluded that the distribution of marron was approximately 20 river kilometres upstream of the point identified by Morrissy (1978). Taylor and Nickoll (2000) again resampled the sites used by Morrissey (1978) between 1998 and 2000, and identified the upper distribution of marron identical to Nickoll and Horwitz (2000) in December 1999, but downstream of Morrissy's (1978) point in April 1999, a further reduction of 25 km of range (a total range reduction of approximately 175 river kilometres in the Blackwood River since European settlement). The differences among the surveys are likely due to seasonal changes and further range reduction.

Some of the variation in marron distribution may be attributed to climatic events (e.g. changes in rainfall volumes and timing, which influence water quality), the vagaries of sampling (e.g. significant variation in catch rates at a site among nights (C. Bird pers. obs.)) and some of the discrepancies are likely to be due to the different definitions of marron range. For example, adult marron can tolerate a range of salinities (Morrissy 1978, Lawrence and Jones 2002) and other parameters; however, it is uncertain if marron can complete their life cycle in waters with a salinity greater than 4‰. Thus, the upstream distribution of marron may vary among authors simply due to the capture of a few large individuals that are incapable of reproducing (Morrissy 1978) (i.e. ecologically extinct) and thus are not truly reflective of the distribution of self sustaining populations of marron. For example, the most upstream distribution of marron identified by Taylor and Nickoll (2000) from December 1999 was comprised of three marron, all above reproductive size. In March 2000, the highest upstream site recorded was based on the capture of a single marron (Taylor and Nickoll 2000). Further, the highest upstream site of significant marron populations (the average CPUE (catch per unit effort) of legal size marron as recorded from the recreational fishery, approximately 5 marron per person per day) that may be targeted by recreational fishers was likely to be Bridgetown Pool, approximately 175 km downstream of the pre-European distribution of marron.

Future issues

Various measures of fishery-dependent productivity indices (total estimated number of marron landed and catch per unit effort) have shown a decline over the past three decades. The decline may be attributed in part, to the impacts of recreational fishing and the numerous changes in management designed to reduce fishing efficiency (CPUE). It is likely that significant and broad-scale reductions in marron range have had major impacts on the Recreational Marron Fishery.

The reduction in the distribution of marron reported in this chapter appears a result of changes in water quality, mainly due to anthropogenic influences in the upper areas of catchments coupled with the inverse salinity profile (Fig. 3) of many of these rivers (Morrissy 1974). However, water quality is also impacted by rainfall patterns, with marron walkouts and fish kills reported during intense periods of summer rain (Morrissy 1978, Smith et al. 2005). Climate prediction models used by CSIRO and Bureau of Meteorology (BOM) have indicated that rainfall patterns are likely to be significantly affected in southwestern Australia in the future. Recently, the CSIRO concluded that southwestern Australia will receive less rainfall, with a higher incidence of summer rain, a result of global warming and climate change (Whetton et al. 2005).

The likely impacts of climate change to marron are a further reduction in range. It is likely that marron stocks in marginal upstream areas will decline (via recruitment failures, leading to ecological extinction, as reported in some areas by Morrissy 1978). This will likely lead to further declines in the productivity of the Recreational Marron Fishery, as indexed by total catches and CPUE marron. In these types of scenarios, managers of the Recreational Marron Fishery may consider further reductions in effort or bag limits, or close the entire fishery, removing one form of impact on marron stocks (recreational fishing). However, it is unlikely that the complete and permanent closure of the Recreational Marron Fishery will have any significant and lasting impacts in regard to maintaining the present distribution of marron or survival of all stocks.

One of the major reasons for the pessimistic outlook for the impact of fisheries management interventions on the sustainability of the Recreational Marron Fishery is that other management agencies are involved with surface water management. For example, the Water Corporation (WC) of Western Australia is responsible for the supply and quality of potable water for the Perth Metropolitan area. In response to a drying climate (significant reductions in southwestern rainfall since the mid 1970s), WC undertook a massive dam refurbishment programme (see Beatty et al. 2003, Molony et al. 2005). This included the refurbishment of dam basins and installation of pipelines to network southern dams into the Perth Water grid for future supply to the Perth Metropolitan area. The WC has worked closely with the Department of Fisheries to reduce the impacts on aquatic biodiversity and recreational fisheries within dams undergoing refurbishment (e.g. Molony et al. 2005). However, if water within the dams is used to supply the metropolitan grid, the policy of WC is to close the dam and catchment to human contact, reducing the risk of bio-contamination. This closes a dam to all recreational activities involving direct contact with water within the basin, including marron fishing. This effectively results in areas of the Recreational Marron Fishery becoming permanently closed.

The continuation of the closure of public dams in the near future (e.g. Loguebrook Dam, Wellington Dam) as suggested by WC will result in the reduction and/or displacement of fishing effort. It is more likely that total effort in the Recreational Marron Fishery will decline if dams are closed, as access to the banks of dams is easier than the access to river banks. The closure of dams will therefore reduce total Recreational Marron Fishery effort and thus total catches.

Additionally, the CPUE from dams is higher than for rivers (see Chapters 2 and 4). This is due, in part, to the ease of access to dams. Additionally, the use of scoop nets, with their higher efficiency (Chapter 2), also resulted in higher CPUEs in dams than in rivers. Thus, further dam closures, in conjunction with gear restrictions, will also reduce the CPUE of the Recreational Marron Fishery.

However, dam closure, in conjunction with appropriate management of water quality in the basin, can benefit marron and aquatic biodiversity by maintaining a pool of good quality water behind the wall; even in severe periods of limited rainfall and water demand. Thus, repositories of marron stocks could be maintained and protected (as WC patrols closed dams and catchments) in dam basins, maintaining genetic diversity and southwestern biodiversity. Although the formal management of the water in dam basins for this purpose has previously been suggested (e.g. Molony et al. 2005), it has yet to be agreed upon.

The impact of a drying climate is also likely to further reduce the upstream distribution of marron. This is due in part, to the further salinisation of the upper reaches of rivers (Beresford et al. 2001, Morgan et al. 2003) as saline groundwater reaches the surface and remains undiluted due to limited rains.

In addition, it is likely that there will be a further reduction of water in river systems, due to the effects of regional and localised groundwater extraction, farm dams capturing water, and the licensed pumping of water from rivers for irrigation purposes. With less surface and groundwater reaching rivers, it is likely that upstream pools that maintain marron and other aquatic species during summer, will be reduced, which would in turn reduce the upstream distribution of many aquatic species. In addition, the forecast for an increased likelihood of intense summer rains is also likely to reduce water quality in upstream reaches, resulting in recruitment failures and/or marron kills (Morrissy 1978), further reducing the upstream range of marron.

In order to properly monitor long-term changes in marron distribution and abundance within river systems, key rivers (~12) need to be surveyed using standardised methods similar to the 2007 survey of the Moore River (Fig. 5). It is critical that dialogue is opened among management agencies responsible for all facets of freshwater management in southwestern Australia, in order to maintain aquatic diversity (including the flagship species, marron, Nickols and Horwitz 2000) and the Recreational Marron Fishery. It is hoped that fishery managers can use the information in this chapter to raise awareness in all natural resource management agencies, in order to generate positive outcomes for the management of freshwater systems in Western Australia. This may allow the paradigm shift in management from single agencies to true catchment-scale ecological-approaches to fishery and freshwater management in southwestern Australia.

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Table 1. A summary of the history of marron translocation in Western Australia (from Morrissy 1978). Major dams and rivers within each of the south-western catchments are identified. Catchment numbers refer to the numbers allocated by state water managers and are arranged from south-east to north-west. Grey block indicates original, pre-settlement distribution.

Catchment	Major Dams	Major Rivers
601: Esperance Coast		Marron unofficially translocated to many waters in the catchment during the 1960s
602: Albany Coast	Angove Dam	Angove Ck. (1939) Moates Lagoon (1940) Kalgan R. (1931)
603: Denmark Coast	Denmark R. Dam	Denmark R. (1914)
604: Kent River		Kent R. (1914) Bow R. (1914)
605: Frankland River		Frankland R. Gordon R.
606: Shannon River	Shannon Mill Dam	Walpole R. Inlet R. Deep R. Shannon R. Gardner R. Meerup R.
607: Warren River	Big Brook Dam	Warren River
608: Donnelly River	Karri Valley Dam	Donnelly R.
609: Blackwood River	Cowan Dam	Scott R. Blackwood R.
610: Busselton Coast	Nine Mile Dam	Margaret R. Capel R.
611: Preston River	Glenn Mervyn Dam	Preston R.
612: Collie River	Harris River Dam Wellington Dam	Collie R. Brunswick R.
613: Harvey River	Harvey Dam Stirling Dam Logue Brook Dam Samson Dam Drakesbrook Dam Waroona Dam	Harvey R.
614: Murray River	Sth Dandalup Dam Nth Dandalup Dam Serpentine Dam (1940)	Murray R. (1913, 1938, 1940, 1961) Sth Dandalup R. (1961) Nth Dandalup R. (1954, 1961) Serpentine R. (1940)
615: Avon River.		Avon R. Dale R.
616: Swan Coastal	Canning Dam Wungong Dam Churchman Bk. Dam Mundaring Weir	Canning R. (1913, 1940)
617: Moore-Hill Reservoir		Moore R. (1947) Lake Yanchep (1932)
701: Geraldton		Chapman R. (1969)

Table 2. Summary of the ranges of water parameters in which marron can survive. Note that some of these references refer to field data, while others are based on laboratory or pond trials.

Variable	Range	Data Source	Reference
Temperature	12 – 25 °C 15 – 30 °C 10 – 30 °C (24 °C)	Field data Field data Laboratory trials	Beatty 2000 Morrissy 1974 Morrissy 1990, Lawrence and Jones 2002.
Salinity	0-17000 $mg.l^{-1}$ (0-17‰) (6,000-8,000 $mg.l^{-1}$) (6-8‰)	Laboratory trial for upper lethal limit	Morrissy 1978 Morrissy 1990, Lawrence and Jones 2002
Dissolved Oxygen	5.0 - 6.0 $mg.l^{-1}$ > 6.0 $mg.l^{-1}$	Laboratory trial Pond trial	Morrissy et al. 1984. Lawrence and Jones 2002
pH	6.0-9.0	Pond trial	Lawrence and Jones 2002

Table 3. Summary of the fishery independent survey of marron range, 2004. #US, number of marron sampled less than 55.0 mm OCL; #LS, number of marron sampled greater than 55.0 mm OCL;

Date	River	Site	No. of nets	pH	T°C	S‰	#US	#LS
19/4/2004	Tone	Mandalup Rd	10	8.2	17.5	4.7	0	0
19/4/2004	Tone	Mirinup Rd	10	7.9	18.4	6.4	0	0
19/4/2004	Tone	Longlish pool	10	7.7	18.8	4.4	2	0
19/4/2004	Tone	Muir highway bridge	6	7.6	17.7	3.1	1	0
19/4/2004	Tone	Chindilip Pool	8	7.6	17.9	3.6	5	0
20/4/2004	Tone	Mandalup Rd	8		17.9		0	0
20/4/2004	Tone	Orient Road	20	8.7	18.1	10.0	0	0
22/3/2004	Kalgan	Woogenilup Rd	33		24.4		0	0
23/3/2004	Kalgan	Woogenilup Rd	16		24.0		0	0
17/3/2004	Blackwood	Warner Glen: upstream	56		21.4		10	7
16/3/2004	Blackwood	Warner Glen:downstream	60		22.5		0	0

Figure 1. Approximate changes in the distribution of marron (Figure modified from Morrissy (1978) and Molony et al. (2002).

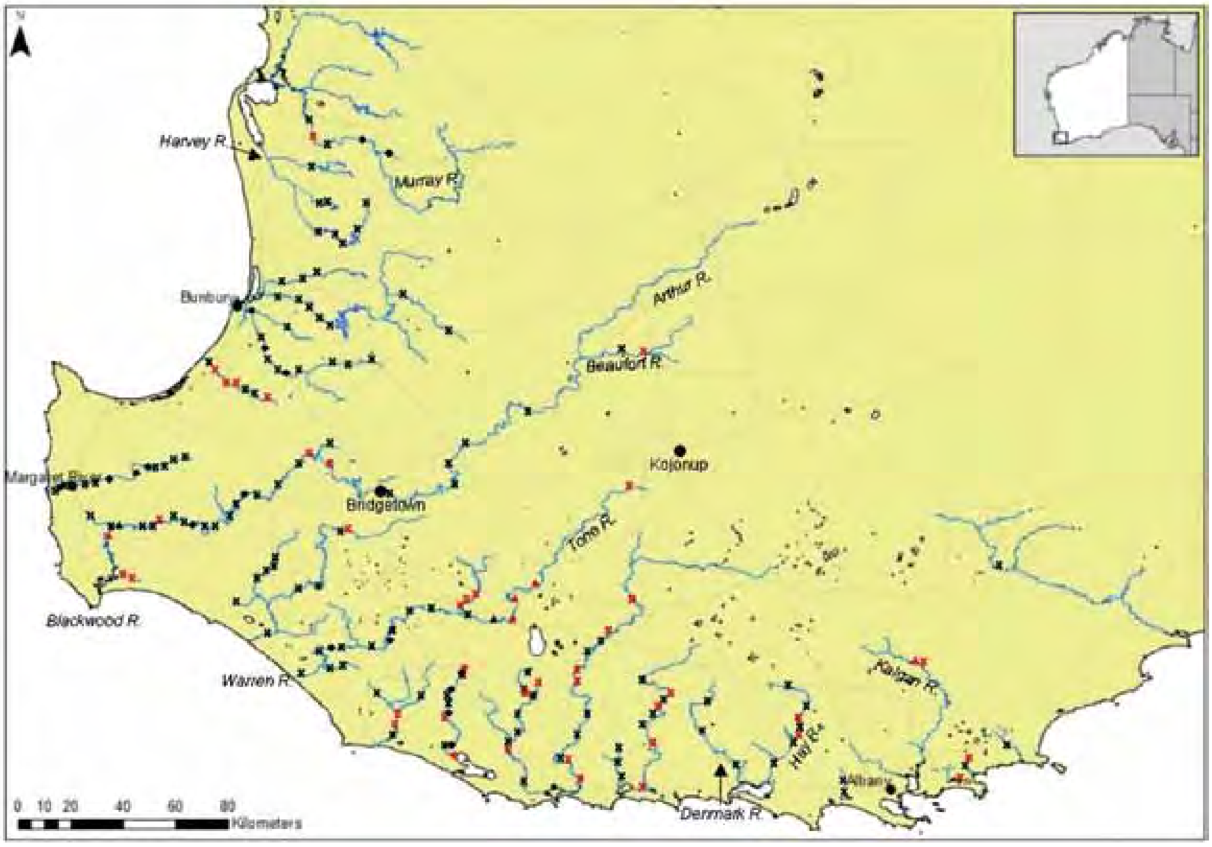

Figure 2. Present distribution of marron in the rivers in the southwest of WA based on logbook holder and research surveys. Red symbol = marron absent, black symbol = marron present, cross = logbook holder survey, triangle = research surveys this study (drop nets), circles = research surveys de Graaf unpublished data 2006/2007 (traps).

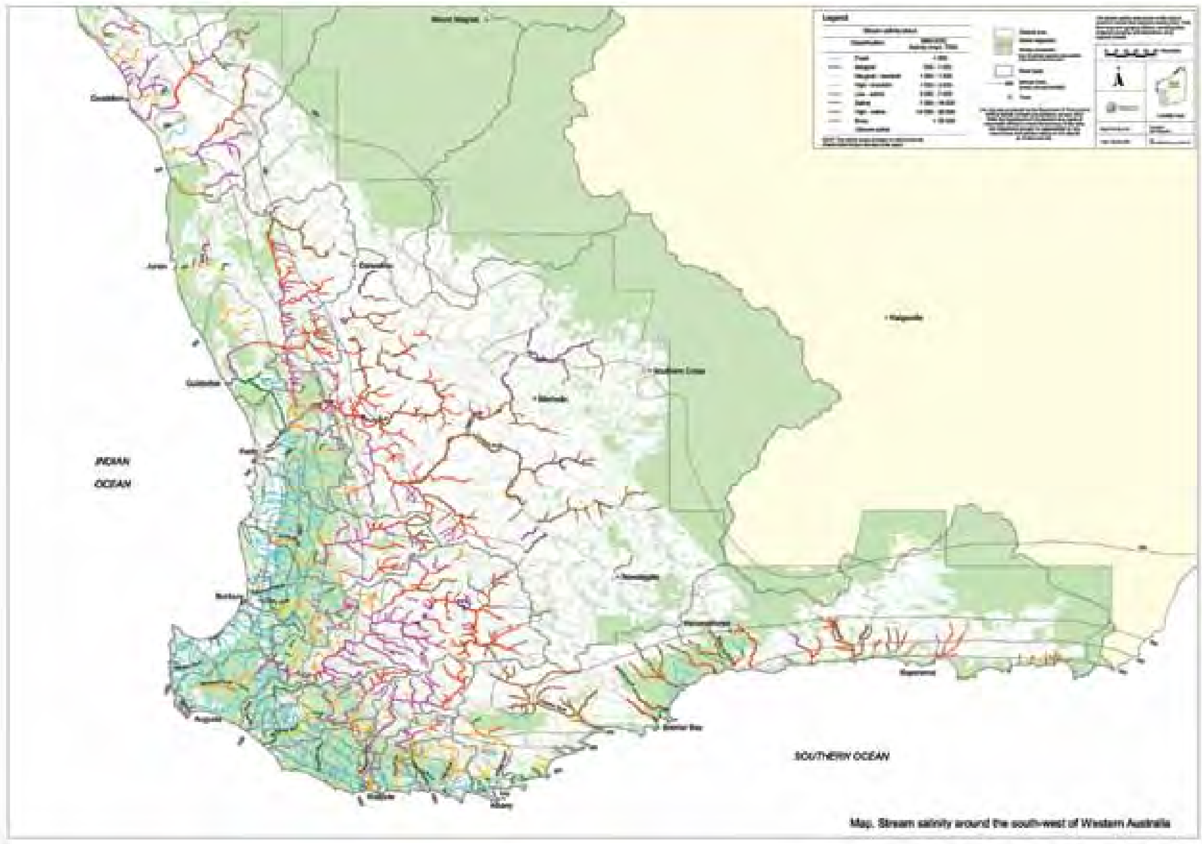

Figure 3. Stream salinity around the south-west of Western Australia (map provided by Department of Water/Mayer et al. 2005).

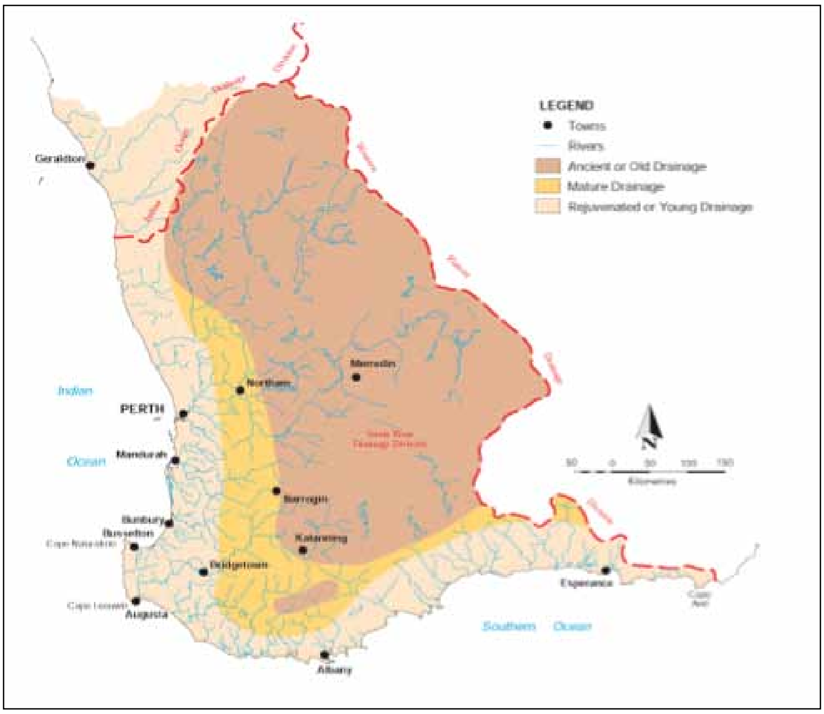

Figure 4. Classifications and limits of major drainage types in the south-west of Western Australia. (map provided by Department of Water).

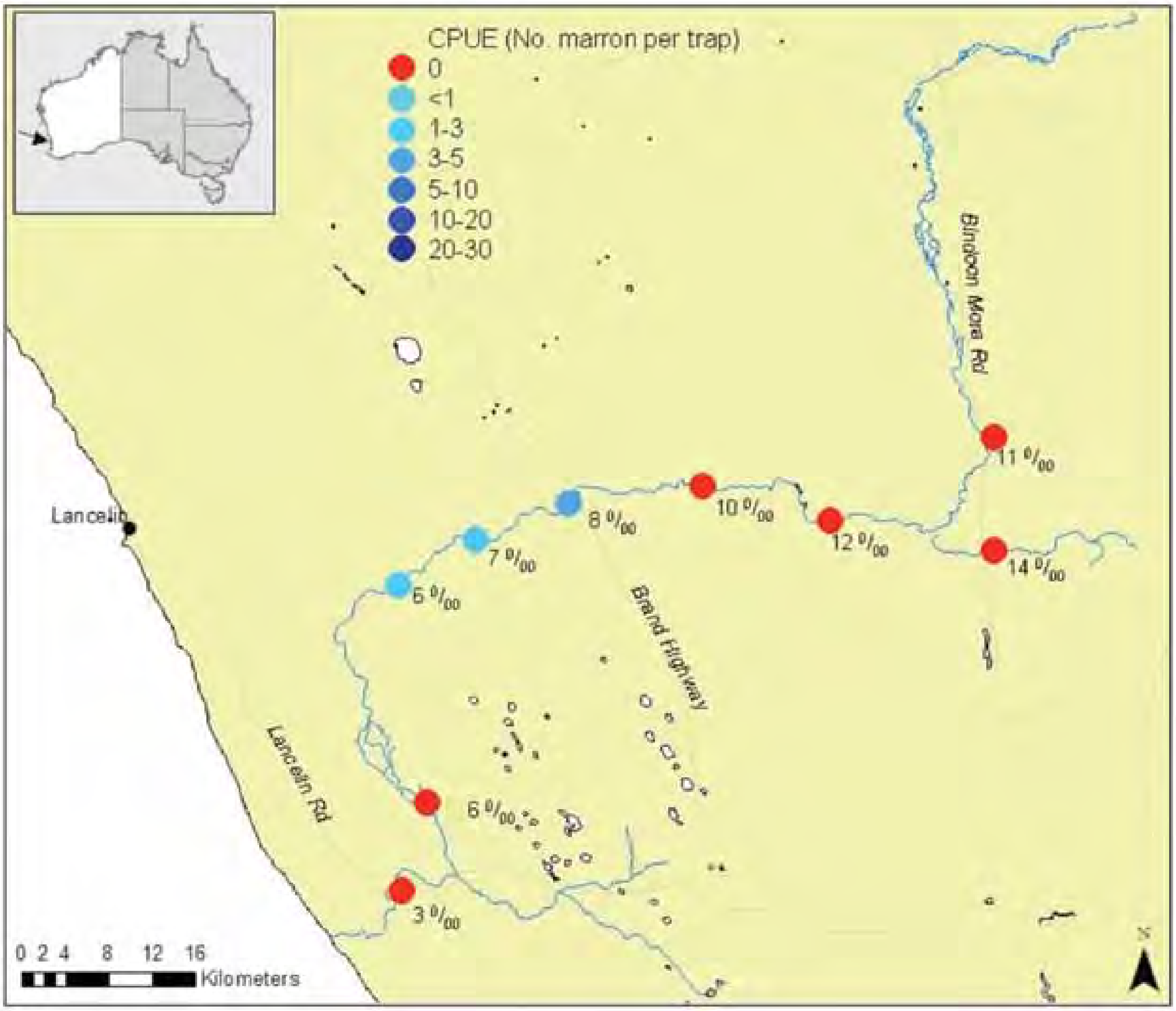

Figure 5. Distribution and abundance of marron in the Moore River in August 2007. Note: the high salinities throughout the system.

2.0 Evaluation of relative gear efficiency and standardisation of long-term catch per unit effort from a recreational crayfish fishery for marron (*Cherax cainii*) in southwestern Australia.

B. Molony, C. Bird, S. Beatty, V. Nguyen and I. Wright

2.1 Introduction

The Recreational Marron Fishery operates in a large number of river, creek, lake and dam sites within 12 major catchments between Hutt River in the north (114.6ºE, 28.7ºS) to Esperance (121.9ºE, 33.8ºS) in southwestern Australia (Molony et al. 2002) (Fig. 1). While including a large number of discrete stocks, the Recreational Marron Fishery is broadly divided into river sites and dam sites as the characteristics of marron stocks in most dams are similar (i.e. relatively high catch rates with most marron just over legal size, 55.5 mm orbital-carapace length (OCL)), as are most marron stocks in rivers (lower catch rates than dams but individual marron are generally larger) (Molony and Bird 2002).

Monitoring of the Recreational Marron Fishery has occurred via three techniques. Fishery independent surveys (i.e. research surveys) have occurred both pre and post season at a subset of sites (typically five per year), with several sites being regularly surveyed since the early 1970s. Among other variables collected, the number and size distribution of marron from a standard area (approximately 1,000 m of bank in dams; both banks of 80 m reach in rivers) have been assessed. Annual telephone surveys have been undertaken shortly after the end of each season with a random sample of between 200 and 800 licence-holders being contacted annually and interviewed about their catch and effort from the previous season. From telephone survey data, CPUE estimates are derived for both rivers and dams. Finally, a volunteer logbook programme has operated since 1971, with between 35 and 130 logbook returns per year. Logbook holders document the details of each recreational fishing trip (e.g. marron size, sex, capture location, fishing effort).

A general decline in total estimated catch and catch-per-unit effort of marron (CPUE, marron. day^{-1} per fisher) has been recorded since the mid to late 1970s (Morrissy 1978a, Morrissy et al. 1984, 1990, Molony and Bird 2002, Molony et al. 2002, Molony 2003, 2005) (Fig. 2). The decline in CPUEs since the early 1970s has resulted in a range of management interventions, mainly involving reductions in the length of the Recreational Marron Fishery season. The length of the Recreational Marron Fishery season was reduced from approximately 6 months (early 1970s) to approximately 55 days between 1990 and 2002 and to 16 days from 2003. In addition, a two-year closure of the Recreational Marron Fishery was implemented in 1988–1989, with a review of management of the Recreational Marron Fishery during the closure (Anonymous 1988). On re-opening in 1990, a significantly shorter Recreational Marron Fishery season and other changes in legislation were implemented, including restrictions in gear types. Since 1980, only three gear types have been legally permitted for use within the Recreational Marron Fishery; scoop nets (SC), bushman's snares (SN) and drop-nets (DN) (see Molony et al. 2002 for gear details).

The Department of Fisheries, Western Australia (DoF) has promoted the use of SN (a wire noose on a long stick or pole (Molony et al. 2002)) as it requires more skill to catch marron using a SN than with a SC or DN (www.fish.gov.au). Further, it has been assumed that the average CPUE of marron by SN, and therefore fishing mortality rates, are lower than for other gear types as only a single marron can be captured at a time with SN. The incremental legislating of SN as the only legal marroning gear permitted at seven irrigation dams and at three river sites was applied between 1990 and 2003 (C. Syers, DoF, pers. comm.). The legislation and encouragement of the use of SN was aimed at increasing the sporting value of marron fishing, reducing effort on under-sized marron (as fishers are more likely to select larger marron to snare) and was based on the assumption that snares were less efficient than the others gear types (SC, DN).

Two issues arise from the legislation and promotion of SN in the Recreational Marron Fishery. Firstly, a formal comparison of the relative efficiency (i.e. catchability) of all three gear types has not been performed and thus the assumption that SN are less efficient than DN or SC has not been tested. If there are differences in efficiency among gear, the raw estimates of CPUE for the Recreational Marron Fishery (Fig. 2) may be misleading. That is, the long-term negative trends in CPUE may simply be a result of differences in gear efficiency and changes in the proportional use of the three legal gears through time and not due to declining marron populations. Additionally, anecdotal reports from logbook holders have indicated that SN may actually have a similar catchability to other gears, after an initial learning period of SN techniques.

This chapter describes an *in-situ* comparison of the relative catchability of the three legal gear types in the Recreational Marron Fishery and a comparison of catches by each gear type (i.e. size at 50% recruitment to each gear, sex ratio). The catchability of each gear type in rivers and dams were used to standardise the historic CPUE data obtained from logbook data and telephone surveys, to allow a re-interpretation of the long-term trends in CPUE of the Recreational Marron Fishery.

The overall aim of this paper is to provide managers of the Recreational Marron Fishery with a set of CPUE data standardised for differences in catchability and proportional use of gears in order to better assess the long-term CPUE trends in the Recreational Marron Fishery. This will permit the estimation of the proportion of the long-term CPUE decline that is attributable to differences in gear efficiency and proportional use of the gears by recreational fishers.

2.2 Methods

Gear catchability trial

Catchability is likely to vary among the three gears. In addition, catchability is likely to vary between river and dam sites due to differences in bank slope, shoreline structure, access and water clarity. Five sites (two river sites and three dam sites) were selected to estimate the relative catchabilities among gears in both rivers and dams. River sites were chosen on the basis of historically high effort reported from telephone and logbook surveys and access to adequate bank length to allow multiple gears to be used by multiple fishers. The two sites were the lower Margaret River (LMR) (33°59'S, 114°59'E) and the Warren River National Park (WRNP) (34°48'S, 115°90'E) (Fig. 1). Both rivers were legislated as SN only; Warren River in 1990 and Margaret River in 1993.

Most irrigation dams within the Recreational Marron Fishery have easily accessible banks due to clearing by dam managers (Molony 2005). Three dams were selected on the basis of historically high effort. Wellington Dam (33°24'S, 115°58'E) (Fig. 1) has received greater than 50% of total dam effort for the Recreational Marron Fishery each season since 2000. Harvey Dam (33°05'S, 115°56'E) and Big Brook Dam (34°25'S, 116°02'E) (Fig. 1) populations are subject to large amounts of fishing effort. All three dams have also been legislated as SN only in 1994 (Harvey Dam), 1996 (Wellington Dam) and 2003 (Big Brook Dam).

The gear catchability trial occurred on a single night at each site between 17^{th}–21^{st} November 2003, with the exception of Warren River, which was sampled on the 22^{nd} of March 2004. These periods allowed the trial to occur well before or well after the 2004 Recreational Marron Fishery season (24^{th} January–9^{th} February 2004) and corresponded with waning moons, periods associated with high levels of marron activity and increased catch rates (Morrissy and Caputi 1981).

At each site, between four or five volunteer fishers were provided with a standard scoop net (SC), a standard snare (SN) or ten standard drop nets (DN) (see Molony et al. 2002 for details of gear design). Each fisher was assigned a section of bank approximately 300–1000 m, separated by at least 100 m from adjacent fishers to maintain independence among adjacent fishers. Each site was divided into a number of sub-sites, each separated by at least 25 m from its neighbouring sub-site. Marron are usually attracted to baits within 10–15 m (Morrissy and Caputi 1981, Molony et al. 2002). Thus, the distance between sub-sites ensured their independence. Each site was assigned as either SC, SN or DN in rotating order. Such assignment of gears ensured that differences in abundance among sites within a night would be randomised among gears. Depending on the length of fishable bank at each site, between 3 and 10 sites were used by each fisher for each gear type (i.e. between 9 and 30 sites per fisher per night). This resulted in a total of 45–120 sub-sites being sampled per night. The bait for all gears was chicken layer pellets laced with blood and bone fertiliser, a standard research bait and widely used by marroners (Morrissy 1989, Molony et al. 2002). For each SN or SC site, a standard bait was set close to the bank (within 2–3 m) to permit the use of SN and SC which are limited by the length of the poles (approximately 2 m). Baits (approximately 100 g) were fixed within a stocking net and tied to the bank. A standard marron drop net (Morrissy 1989) was used for each DN sub-site, set with five metres of rope and baited with approximately 100 g of standard bait. Thus all three gears were fishing a similar distance from the bank and bait type and size were standardised among gears and fishers (and allowed easy retrieval and disposal of baits at the end of each night).

Baits were set by 16:30 hours at river sites and by 18:30 hours at dam sites. The difference in timing between the habitats was due to marron becoming active when light levels decline. In river locations, due to shading by riparian vegetation, marron generally become active earlier than in dams and volunteer logbook holders report an earlier start to marroning in rivers than in dams (C. Bird, unpublished logbook data).

Fishing commenced approximately 60 minutes after baits were set. For SC, the standard technique is to quickly scoop any marron surrounding a bait. For SN, single marron are snared from a posterior direction. For DN, the rope is retrieved rapidly and all marron removed before the DN is reset. Each bait was re-sampled at 45–60 minute intervals for a total of three samples per night. Fishers were allowed their discretion about how many attempts they made to capture marron by SC or SN from each of the individual baits at each time. Marron captured by each gear type, on each pass, by each fisher, were kept separate in moistened Hessian bags. Marron were measured (OCL ± 0.1 mm) and sexed. All marron were returned to the site of capture at the end of each night.

Research surveys

Research surveys occurred both pre-season and post-season in all years. As the season length and timing has varied since 1971, the timing of the surveys has also varied. However, since 1990 when the season length was reduced to approximately 55 days during January and February, pre-season surveys generally occurred in November and post-season surveys in March each year, during the new moon phase of the lunar cycle. Surveys in dam sites used a standard SC with a smaller mesh than the present legal SC, therefore catching well below legal size marron (pre-fishery recruitment). Approximately 1000 m of bank was baited at 10 metre intervals with approximately 100 g of bait per station, a total of 100 baits per site. Three passes were made across the baits at hourly intervals and as many marron as possible were captured during each pass. At river sites, baited drop nets (n = 15) with a much smaller mesh than legal DN (Morrissy 1989) were set at approximately 10 m intervals along both banks and three hauls at hourly intervals were made. All marron captured were retained and similar data as described for the gear trial were recorded. All marron were returned at the end of each night.

Telephone surveys and logbook data

Telephone surveys were generally undertaken within four weeks following each Recreational Marron Fishery season. Licence holders (n = 200–800 per year, randomly selected) were contacted and a range of questions asked about their activity in the previous Recreational Marron Fishery season, including the number of marroning trips, the location (dam or river), the gear(s) used and the number of marron captured.

Between 35 and 130 logbooks were completed each season by volunteers throughout the Recreational Marron Fishery. The number of trips completed by logbooks holders and their catches varied among years but estimates of CPUE were generally higher than those estimated from the telephone surveys.

CPUE estimates from telephone and logbook data were calculated per respondent for both telephone and logbook data for rivers and dams separately and the annual average for each series calculated. The proportional use of gear was also calculated for telephone and logbook surveys separately, independent for both rivers and dams. Estimates of proportional gear use existed for both rivers and dams from recent telephone surveys undertaken (2000–2004) and for rivers and dams for the logbook holders between 1990 and 2003 (14 years of data). The exceptions were in 1975 when no logbooks were distributed and for the closed seasons of 1988 and 1989.

Data analysis

For the gear catchability trial, the number of marron per gear type was pooled within rivers and dams due to the low numbers of marron captured per night (range: 29 –97). Chi-square (χ^2) analyses were used to determine if the number of marron captured in rivers or dams varied from an even distribution among the three gear types. If significant differences were found, the relative catchability of each gear type in rivers and dams was estimated by dividing the proportion of marron captured by a gear type by the proportion of marron captured by the gear type with the highest CPUE, standardising the CPUEs of each gear type to a maximum of 1.00 separately for rivers and dams (i.e. relative catchability).

The size of 50% recruitment of marron to each gear in rivers and dams were determined by a logistic regression. Chi-square (χ^2) analyses were also used to determine if the sex ratio of marron captured by the three gears varied from a 1:1 ratio, typical of marron populations (Beatty et al. 2003, C. Bird unpublished data).

Standardisation of CPUE series

Relative catchabilities estimated for each gear from the gear trial were applied to the time series of nominal CPUEs for rivers and dams for logbooks (from 1990) and telephone survey (from 2000), taking into account the estimated proportional use of the three gear types via;

$$sCPUE_j = nCPUE_j * \left(\sum_{i=1}^{i=3} (use_{ij}/catchability_i)\right)$$

where $sCPUE_j$ is the standardised CPUE estimate for rivers or dams for telephone or logbook data for year j, $nCPUE_j$ is the nominal CPUE estimate for year j (as presented in Fig. 2), use_{ij} is the estimated proportional use of gear type i for year j and $catchability_i$ is the relative catchability of gear type i (estimated from the gear trial). Each standardised CPUE series was normalised by dividing by the mean of each CPUE series. Finally, each standardised and normalised CPUE series was multiplied by the mean of the nominal CPUEs for each series, effectively producing a standardised CPUE series.

Finally, logbook CPUE data were compared to the research survey data (numbers per night) using the techniques of Harley et al. (2001). This was to determine the relationship between logbook CPUE and pre-season research survey data and to compare the relationship to a slope of 1, providing an overall estimate of bias in the CPUE data. Only a single dam site, (Wellington Dam) provided a time-series of more than nine pairs of logbook and research survey observations (as suggested by Harley et al. 2001). The total number of marron captured per night from research surveys at Wellington Dam were normalised by dividing catches by the maximum catch. Similarly, logbook CPUE estimates from Wellington Dam were also normalised to 1.0. Pairs of data (for each year) were regressed and the relationship compared to regression with a slope 1, which would indicate that logbook CPUE is a good index of relative abundance as determined from the research surveys.

2.3 Results

Significant differences were identified in the number of marron captured among the three different gear types in rivers and dams during the gear trial. In dams, 62 marron from a total of 108 captured at the three sites were captured by SC (57.4%), with 25 captured by DN (23.1%) and 21 by SN (19.4%). The number of marron captured by each gear type in dams was significantly different from an even distribution among gear types ($\chi^2_{[2]}$, P = 6.85 x 10^{-7}). In dams, the catchability of marron by SC was approximately three times that of the other gear types (Table 1).

Of the 146 marron captured from the two river sites, 75 (51.4%) were captured by DN, 46 by SN (31.5%) and 25 by SC (17.1%). The number of marron captured varied significantly from an even distribution among gear types ($\chi^2_{[2]}$, P = 2.37 x 10^{-5}). In rivers, the catchability of marron by DN was approximately 60% greater than the CPUE for SN and triple that of SC (Table 1). The CPUE of the three gear types were clearly not comparable within dams or rivers. Thus, previous trends in CPUE from the Recreational Marron Fishery (Fig. 2) were not likely to be representative of actual changes in abundance.

The size distributions of marron also varied among gear types (Fig. 3). In river sites, the size-distribution of marron captured by DN was much larger than for SC or SN (Fig. 3a). The size of marron at which 50% were recruited to SC was less than legal size at both river sites. The size at 50% recruitment to DN was much greater than legal size at both river sites. The size at 50% recruitment to SN was above legal size in the Margaret River but below legal size in the Warren River. Both SN and SC captured marron at a sex ratio not significantly different to 1:1 in both river sites. In contrast, significantly more male than female marron were captured by DN at the two sites (Warren River, $\chi^2_{[4]}$, P = 0. 0051; Margaret River, $\chi^2_{[4]}$, P = 0. 0325), with a ratio approximating 2:1 (males:females).

At Big Brook and Harvey Dams, the size of marron at 50% recruitment to all gears was greater than the legal size (Fig. 3b), although the low sample sizes did not provide robust distributions. The data was not pooled among dam sites due to the differences in size distributions of marron among sites. For example, nearly all marron captured at Harvey Dam were greater than legal size. Only SN captured marron from Wellington Dam had a length at 50% recruitment to the gear less than legal size. Almost all gears at all dam sites captured marron at a sex ratio similar to 1:1. The exception was marron captured by DN at Wellington dam, which captured significantly more male than female marron, with a ratio approximating 2:1 (males:females). However, the result was only marginally statistically significant ($\chi^2_{[4]}$, P = 0. 0455).

The estimated proportion of gear type used each marron season from the telephone survey and logbook returns varied between rivers and dams through time. DN were the most commonly used gear in rivers for all years since 1990 from both logbook and telephone surveys, accounting for an average of approximately 70% of gear use reported by logbook holders and approximately 55% of telephone survey respondents (Fig. 4). The proportional use of DN by logbook holders was relatively constant since 1990. SN were the next most used gear reported by logbook and telephone respondents (20–40%), with SC accounting for less than 10% of the total effort in most years. Logbook holders reported a higher use of DN and a lower use of SN and SC for all years compared to telephone survey respondents.

Clear differences were seen in the proportional use of gears in dams by both logbook holders and telephone survey respondents since 1990 (Fig. 4). Logbook holders recorded a steady decline in the proportional use of SC from the early 1990s, reducing from approximately 80% to less than 10% in 2002. DN use by logbook holders was relatively stable between 1990 and 1999 and then increased from approximately 20% in 1999 to nearly 40% of reported gear use in 2001, before DN use in dams declined to almost 0% in 2003. The reported use of SN in dams by logbook holders steadily increased from less than 10% in the early 1990s to nearly 90% in 2003. Although a shorter time series, telephone respondents reported similar patterns of gear use to logbook holders between 2000 and 2004 (Fig. 4); that is, a rapid decline in the use of DN and SC and a rapid increase in the use of SN.

CPUE standardisation

Nominal and standardised CPUEs from logbook and telephone data for rivers were similar between 1990 and 2004 (Fig. 5a). Differences between nominal and standardised CPUEs series were less than 5% for any year. The similarity between nominal and standardised CPUE series is likely due to the dominance of the use of DN by river fishers (the gear with the highest catchability), and the relatively stable proportion of gear use in rivers since 1990 (Fig. 4). All four CPUE series for rivers were similar, displaying a decline in river CPUE between 1990–2002, with an increase in CPUE in 2003 of about 30% from 2002 levels. From telephone survey data, the increase in river CPUE continued in 2004 although at a lesser rate than for 2002–2003 (approximately a 9% increase on 2003 estimates). While a general decline in CPUE was recorded in all series since 1990, all series also showed a pattern of increasing CPUEs for 3–4 years before a major decline in CPUE. Thus the decline in CPUE was almost sine-wave like.

Standardised estimates of CPUE for dams displayed a similar downward trend as the nominal data, although the standardised CPUEs were lower than nominal values between 1990 and 1996 (Fig. 5b). After 1996, nominal and standardised CPUEs converged, although both data series continued a downward trend until 1999. From 2000 however, both logbook CPUE series increased, especially after 2002. The increase in the nominal logbook CPUE series was approximately 100% between 2002 and 2003 levels. For the standardised series, the increase between 2000 and 2003 was over 300%. This trend was also evident in the standardised telephone CPUEs, although the increase in CPUE occurred after 2002 and was more modest (about 25%). Much of the recovery is attributable to the major changes in gears proportions used by dam fishers late in the time series (Fig. 4). No increase in CPUE was evident in the nominal telephone CPUE series.

As the pattern of gear use recorded by logbook holders from rivers was stable for all gear types between 1990 and 2003 (Fig. 4) it was assumed that the proportional gear use was similar for the entire monitoring period of the Recreational Marron Fishery since 1971. Standardisation of river CPUE data was performed for the entire river CPUE series (1971/2–2003) using the techniques described above. As expected, the standardised CPUE was similar to the nominal CPUE (Fig. 6). The long-term (greater than 30 year) downward trend in CPUE was still evident displaying a reduction in CPUE of approximately 70% between 1971 and 2002, with some recovery since 2002.

Research surveys

The number of marron captured per night during research surveys at Wellington Dam was highly variable, probably a result of differences in weather conditions (such as rain or strong winds reducing water visibility) and illegal effort (poaching) influencing and/or reducing marron catches per night. A linear fit to the eleven years of normalised research and logbook CPUE data from Wellington Dam had a slope less than unity for nominal and normalised CPUE data (slope = 0.81) and for standardised and normalised data (slope = 0.94) (Fig. 7). This provides evidence of localised depletion (i.e. hyperdepletion – CPUE declines faster than true abundance) of marron during most Recreational Marron Fishery seasons, at least in Wellington Dam.

2.4 Discussion

Differences in gear efficiency and proportional gear use in rivers and dams and the effect of gear efficiency on CPUE have not been taken into account in previously published CPUE data for the Recreational Marron Fishery (Morrissy 1978a, Morrissy et al. 1984, 1990, Molony and Bird 2002, Molony et al. 2002). Thus, previous CPUE estimates are unlikely to be comparable among years, especially in dams where proportional gear use has varied significantly through time since at least 1990 (Fig. 4).

Significant differences in catchability of the three legal marroning gears were demonstrated in both river and dam sites in the Recreational Marron Fishery from in-field trials. In river sites, DN were the most efficient gear with CPUEs three times that of SC and 60% higher than SN. The likely reasons for the high relative efficiency of DN in rivers is that many rivers in southwestern Australia have steep banks and the timing of the Recreational Marron Fishery season is during summer when river levels are at their lowest, making access to the water level difficult. However, DN can be set without fishers needing to access the water-line, while SC and SN require fishers to be at water level. Secondly, rivers are often structurally diverse, containing fallen trees and rocky habitats. Underwater structures can interfere with the use of SC and SN, especially SC as the gear must be moved quickly through the water to capture marron. Thirdly, DN are capable of capturing more than one marron per haul, while SN can only capture a single marron at a time, as is generally the case with SC. Finally, many rivers in southwestern Australia are coloured (tannin-stained) (Penn 1999) reducing visibility; both SN and SC rely on fishers being able to see marron, while DN are not affected by changes in visibility.

In dams, the CPUE of SC was approximately three times higher than either DN or SN. The high efficiency of SC in dams is due to the gently sloping and shallow profile of many dam banks and lack of submerged structure as a result of contouring during construction (Molony 2005). Together with the generally good visibility in dams, the gentle slopes of most dam banks allows access to most of the water line around dams, favouring the use of active gears (SC and SN) more than a passive gear like DN. Further, there is the increased likelihood of capturing more than one marron at a time with SC in dams while SN are still limited to a single marron per time.

The size at recruitment of marron varied among gears and sites. More than 50% of marron captured by DN at all sites were greater than legal size (Fig. 3). The rigid-metal base of DN has been tested for the size of retained marron prior to specifying a legal mesh size (Morrissey 1989) and was designed to allow most undersized marron to pass through the rigid-metal mesh. From field trial data, approximately 50% of just-legal sized marron (55.5–59 mm OCL) were lost from DNs fitted with the regulation mesh (Morrissey 1989). The escapement of relatively large marron may assist in the sustainability of marron stocks, as bigger females produce more eggs than smaller marron (Morrissy 1970, Beatty et al. 2003). Fishing quality may also be increased as marron weight increases at approximately the cube of OCL (Molony and Bird 2002). The impacts of fishing on juvenile recruitment may also be reduced as DN captured significantly more males than female marron (a ratio of approximately 2:1) than other gear types at three of the five sites, allowing more females to survive and potentially reproduce in future years. As a result, DN are likely to a have a lesser impact on undersized marron than other gears, and may be a more appropriate gear for the Recreational Marron Fishery.

SC and SN captured marron displayed smaller sizes at 50% recruitment than DN captured marron, although the size of marron at 50% recruitment varied among sites. While high proportions of undersized marron were captured by these gears at all sites except for Harvey Dam, the lower relative catchability of SN compared to SC would reduce the fishery impact on marron stocks by this gear. Thus SC may be a more suitable gear in dams in terms of increasing CPUE. The relatively large size of Harvey Dam marron has been reported previously (Molony and Bird 2002, Molony et al. 2002). The fishery in the Harvey Dam is managed as a trophy fishery under special arrangements (minimum legal size of 65 mm OCL, daily bag limit of 5 marron) due to the large size of marron captured by recreational fishers at this site.

There was little difference between the nominal and standardised CPUEs for rivers since 1990, with similar CPUEs estimated from nominal and standardised telephone surveys (Fig. 5a and 6). The likely reason for the small effect of standardisation is due to the relatively consistent proportional use of the three gear types by river marroners since 1990 (Fig. 4), and the relatively high catchability of the most commonly used gear, DN (Table 1). Thus, differences in gear use and catchability are unlikely to be responsible for the continued decline observed in CPUE in rivers since 1990. Further, there seems little value in standardising the nominal CPUEs for rivers within the Recreational Marron Fishery.

A cycle of river CPUEs was also evident in the data since 1990 (Fig. 5a). A peak in CPUE was recorded in 1994, after two successive years of increasing CPUE. A peak was also evident in CPUE in 1998, again after two successive years of increasing CPUE. In both instances, CPUE after the peak year were reduced by approximately 37% in 1995 and 25% in 1999. An increase in CPUE was again evident in 2003 and 2004. However, evidence of a long-term cycle in the CPUE data for rivers means that the increasing CPUEs recorded after 2002 in all CPUE series may not necessarily reflect recovery (Fig. 5). While the reason for this cycle is unknown, it may correspond to periods of favourable conditions for reproductive success (berry-up rate), juvenile survival and/or adult growth. As the cycle appears to occur every 3–4 years, it appears that events 3 or more years prior to the peaks are responsible and are likely to be environmentally related (e.g. rainfall). However, as the CPUE trends are downward, there is no evidence of stabilisation of riverine CPUEs.

Standardised marron CPUEs for dams were different from nominal logbook CPUEs from 1990. Standardised CPUEs were between 6.5% and 27.5% lower than nominal CPUEs between 1990 and 1996, before converging. The proportional gear use for dams revealed a relatively stable use of SC (the gear with the highest catchability in dams), with a slow increase in the use of SN in this period from approximately 0% to 20% by 1996. After this point, the CPUE series converge, stabilise and then show recovery in the logbook data, coinciding with a major change in gear use. This included a major reduction in the use of SC from approximately 70% in 1997 to less than 10% in 2003. During this period the use of SN (the gear with a low catchability in dams) increased to almost 80%.

In dams, both nominal and standardised logbook CPUE data showed a major recovery after 2001, likely a result of the high use of SN (with a low catchability). While the increase in CPUE is clear, it should be interpreted with caution as both CPUE series for logbook data show a CPUE higher than the daily bag limit (10 marron) in 2003. Further, the standardised telephone data showed only a mild increase in CPUE after 2001, with nominal telephone data showing no change. In addition, the major increase in CPUE may reflect increasing catchability of SN gear by logbook holders after a period of ‘learning’. Thus a future comparison of gear catchabilities is likely to be required in dams to determine if SN catchabilities are increasing with learning.

Nonetheless, all CPUE series for dams show a decline between 1990 and 2000/2001. The standardised CPUE series hds a 50% lower gradient than the nominal series between 1990 and 2001. This suggests that changes in gear use and catchability among gears is accountable for about 50% of the decline in CPUE up until approximately 1996. However, marron CPUEs converged in the late 1990s, suggesting that differences in gear catchability and use were insignificant after this point. Fisher learning of SN skills may be responsible for the convergence of nominal and standardised CPUEs in the mid to late 1990s.

Although accounting for differences in efficiency among gears and changes in proportional use increased the estimated CPUE relative to the nominal estimates (Fig. 5), the long-term downward trends in CPUE remained, especially in the long-term river CPUE series (Fig. 6). Thus changes in gear efficiency and use do not account for the long-term decline in CPUE previously reported in the Recreational Marron Fishery in both rivers and dams.

What has caused a recovery in CPUE in rivers and dams in recent years? In 2002 a major review of the management of the Recreational Marron Fishery resulted in many changes to legislation, including the legislation of all dams and three river sites to SN only, a gear with a relatively low efficiency. This completed the transition to SN-only for all irrigation dams in the Recreational Marron Fishery. As SN are much less efficient than SC in dams (the major gear type in dams for most of the 1990s (Fig. 4), an increased standardised CPUE was expected. The increase in nominal logbook CPUE but not nominal telephone CPUE in dams is likely to be due to the greater experience and skill levels of logbook holders than telephone respondents. For example, logbook holders reached their bag limit (10 marron.day^{-1}) more than twice as often in 2003 (28% of trips) than in 2002 (15% of trips) (C. Bird unpublished logbook information).

The other major change to the Recreational Marron Fishery in 2003 was a reduction in season length from approximately 55 days to 16 days. Fisher behaviour is likely to have changed in that fishers may have fished for more hours per day to ensure their bag limit, as the opportunities to catch marron were reduced due to the shorter season. Again, an increase in hours fished per night in rivers is evident in logbook data in 2003 (C Bird, unpublished logbook information). Thus, a shorter season appears to have altered fisher behaviour, resulting in a longer time spent fishing per day and an increase in the proportion of trips resulting in bag limit atainment (10 marron). The continued increase in standardised CPUE seen in the telephone survey data between 2003 and 2004, may reflect fishers becoming familiar with the shorter season, as the 2004 Recreational Marron Fishery season was the second year of a reduced season.

Hyperdepletion occurs when CPUE declines while actual abundance remains high. Although hyperdepletion is rare in finfish stocks (Harley et al. 2001), hyperdepletion is likely to be common in crayfish species such as marron due to the biology, ecology and behaviour of species (Beatty et al. 2003, 2004), and evidence of hyperdepletion was also recorded in *C. quinquecarinatus,* an endemic crayfish species often found in the same waterbodies as marron (Beatty, et al. 2005).

Hyper-depletion of crayfish stocks as a result of fishing effort is likely. Marron do not tend to move great distances (typically less than 50–100 m) and appear faithful to individual sites (Molony and Bird 2005). Further, as marron are brooders (Beatty et al. 2003) there is limited dispersal of juveniles and thus marron stocks are likely to be self-recruiting. In addition, marron have a relatively long period between hatching and recruitment into the fishery (estimated between 2 years and 4 years, eg. Beatty et al. (2005) Chapter 5). Reducing the length of the season, reduced total effort and therefore total catch (Molony 2003). A shorter season may potentially mitigate the effects of hyperdepletion of stocks (Fig. 7) as total effort in the Recreational Marron Fishery has been reduced from approximately 32,000 trips (2002) to 9,000 trips (2003) with the application of a shorter season (Molony 2003). As less total marron are removed during a shorter season, the hyperdepletion response is also likely to be reduced and it is expected that CPUE will be a better estimate of marron abundance (from research surveys) in the future if the shorter season is maintained. It is recommended that monitoring of catch and effort and standard research surveys be continued in the future in order to test the effects of a reduced season, as the reduced season is likely to remain in force (i.e. adaptive management).

The comparison of gear catchabilities in rivers and dams has other potential uses aside from standardising CPUE series. There is also the potential to use gear efficiencies to assess fisher compliance to gear regulations in some areas of the Recreational Marron Fishery. For example, Wellington Dam became SN-only in 1996. However, the nominal CPUE for Wellington Dam was similar to the nominal CPUE for all dams (SN-only and all gears) estimated from both logbook and telephone survey data (Fig. 8). Thus, despite the expected suppression of nominal CPUE as a result of SN-only as calculated using the gear efficiency information collected in the current trial (Fig. 8), the CPUE in Wellington Dam remained similar to the CPUE from all dams. This indicates that the use of SN only by fishers at Wellington Dam is unlikely to be 100%. This is supported by research surveys of Wellington Dam that revealed a similar OCL-frequency distribution to dams not yet legislated as SN-only (Molony and Bird 2002). Thus, as a management tool, relative gear efficiencies may be able to provide indications of gear compliance at some sites and be used to determine if other management actions (e.g. increasing patrols at some sites) are required. However, this depends on enough information being collected by telephone and logbook surveys for major sites, supported by research surveys.

What is the most appropriate gear?

The standardised CPUE series and size at 50% recruitment to the gears also permitted insight into the appropriateness of gears in rivers and dams in terms of the sustainability of the Recreational Marron Fishery. In rivers, despite DN having an increased CPUE, the recruitment of marron into DN (assessed as size at 50% retention) is above legal minimum size and well above mean size at first reproduction in many sites (Molony and Bird 2002). Thus, the use of DN is likely to reduce the fishery impacts on the reproductive potential of a riverine marron stock. In addition, the use of DN results in an increase in the average size of marron retained by the gear mean, increasing the quality of the fishery. Finally, the removal of relatively large marron may reduce inter-specific competition of marron, likely benefiting survival and growth of smaller, non-retained marron, influencing catches in future seasons.

Although the catchability and CPUE of DN in rivers is higher than for other gears, the nature of most rivers in the Recreational Marron Fishery are such that access to the water level is limited. Coupled with the limited movement of marron, it is likely that the use of static gears like DN results in some areas receiving little or no Recreational Marron Fishery effort, as supported by the continued catches of relatively large marron in rivers compared to dams (Molony and Bird 2002), despite high river effort in the Recreational Marron Fishery (Molony and Bird 2002, Molony et al. 2002, Molony 2003). These areas of little or no recreational effort may act as refuge from fishing for some marron stocks, assisting in the maintenance of stocks.

At dam sites, most of the banks are accessible to marroners due to clearing and contouring during construction (Molony 2005). Thus SC are much more efficient than other gears in dams. Declaring all dams to SN-only, with a lower catchability relative to SC, may reduce fishing impacts on marron stocks dams. SN may also increase the fishing experience as they require higher level of fishing skill than the other techniques. In addition, as only a single-marron can be captured by SN at a time, fishers are more likely to capture fewer, larger marron by SN, thus increasing the fishing value. DN are not an appropriate gear for dams as most areas in dams have shallow banks making the use of DN ineffective. SN may also reduce the impacts of localised depletion observed in dams due to a reduced catchability, assuming that each marroning trip involves a similar amount of time. However, the size of 50% recruitment of marron to SN gears was not always above minimum legal size at all sites examined. Thus the appropriateness of SN in dams may need to be re-considered in the future, especially if increased learning by fishers results in an increased catchability by this gear.

Although relative gear efficiencies and proportional changes in gear use have revealed some differences between standardised and nominal CPUE trends, the overall downward trends still remain (Figs. 5 and 6). Thus, most of the declines in CPUEs are not a result of changes in gear use and differences in catchabilities, especially in riverine systems Why have CPUE trends continued to decline in the Recreational Marron Fishery? It is likely due to major environmental changes that have occurred in southwestern Australia which have impacted on aquatic ecosystems and therefore marron populations.

One major environmental change is the salinisation of many catchments in southwestern Australia as a result of large scale clearing of vegetation, particularly in the upper areas of catchments (Pen 1999, Chapters 1 & 3). Salinisation reduces the extent of marron habitat (marron do not survive well in water with salinities above 8‰ (Morrissy 1974)) and thus the range of marron has been reduced (Morrissy 1978b). With a reduction in marron range in rivers, effort in the Recreational Marron Fishery is concentrated over a smaller area and thus the effects of fishing are intensified. A likely outcome is the reduction in average CPUE, as Recreational Marron Fishery effort is focused in smaller areas of favourable to marron in rivers and the limited number of dams open for marron fishing.

Secondly, there has been a major regime shift in rainfall patterns over much of southwestern Australia. Since the mid 1970s, there has been a reduction in rainfall by approximately 25% (www.dar.csiro.au/earthsystems/jpegForWeb1999/swwa.htm, Molony et al. 2002). Rainfall increases runoff and therefore nutrient supply into rivers and dams (increasing energy supply and therefore productivity of systems), increases space in aquatic environments (reducing inter and intra-specific interactions and competition) and dilutes predators. Reduced rainfall can therefore have detrimental effects including a likely reduction in the total number of marron (due to increased competition, predation and juvenile mortality) and/or the abundance of legal-sized marron in the Recreational Marron Fishery (due to reduced energy input into waters, reducing productivity and therefore growth-rates of marron). Further, a reduction in rainfall results in higher demand for water extraction for human use (e.g. potable water supplies, agriculture irrigation, etc.). In response, the major manager of water supply in Western Australia (Water Corporation of Western Australia) has closed some dams to recreational activities including marron fishing, shifting effort to fewer locations and therefore reducing CPUE.

The overall impact of environmental changes and the reduction in range of marron and Recreational Marron Fishery are the subjects of ongoing research. However, the comparison of gear efficiencies and the standardisation of CPUE series has allowed the effects of differences in catchabilities among gears to be assessed and dismissed as a factor accounting for the long-term decline in CPUE in the Recreational Marron Fishery, as the declines are still present at a similar rate in the standardised CPUE series since the mid 1970s in rivers and since at least the mid 1990s in dams.

2.5 References

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Table 1. Summary of the catches of marron and relative catchability of gears (DN-drop net, SC-scoop net, SN – snare). The relative catchability of gears was calculated from the data collected from the three dam sites (Harvey, Wellington and Big Brook) and two river sites (Warren River and Margaret River).

Relative efficiency	DN	SC	SN
Dams			
Number of marron captured	21	62	25
Relative catchability	0.209	0.596	0.195
Relative catchability compared to SC	0.35	1	0.328
Rivers			
Number of marron captured	75	25	46
Relative catchability	0.462	0.195	0.343
Relative catchability compared to DN	1	0.421	0.742

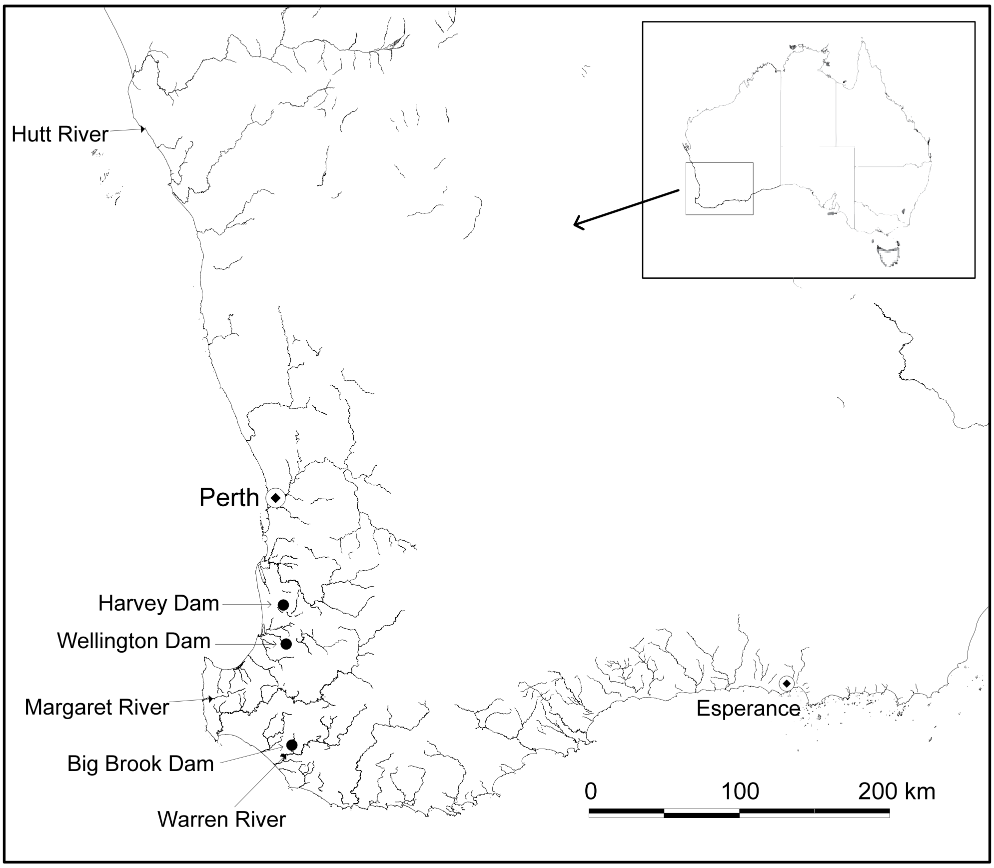

Figure 1. Map of south-western Australia showing the location of sites used in the gear efficiency trial.

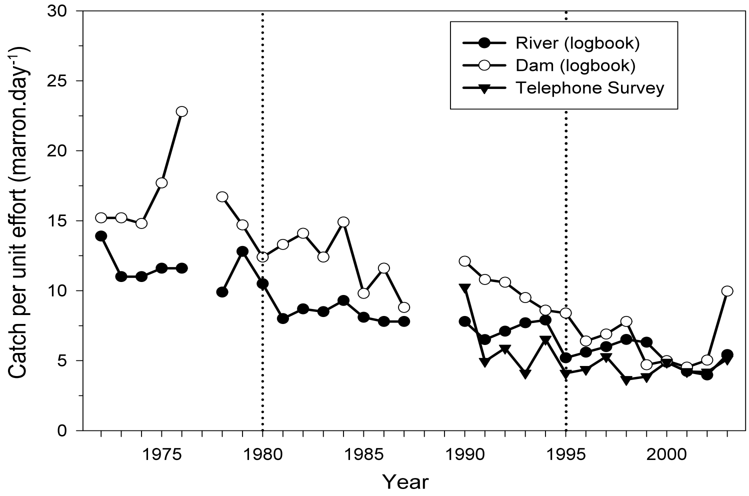

Figure 2. Nominal catch per unit effort (marron per day) from various sources (modified from Molony 2003). The two vertical lines indicate changes in bag limits in 1980 (reduced from 30 $marron.day^{-1}$ to 20 $marron.day^{-1}$) and 1995 (reduced to 10 $marron.day^{-1}$). In 2003 a bag limit of 5 marron per day was introduced at a single site (Harvey Dam). No logbook data was collected in 1975. A closed season occurred in 1988 and 1989.

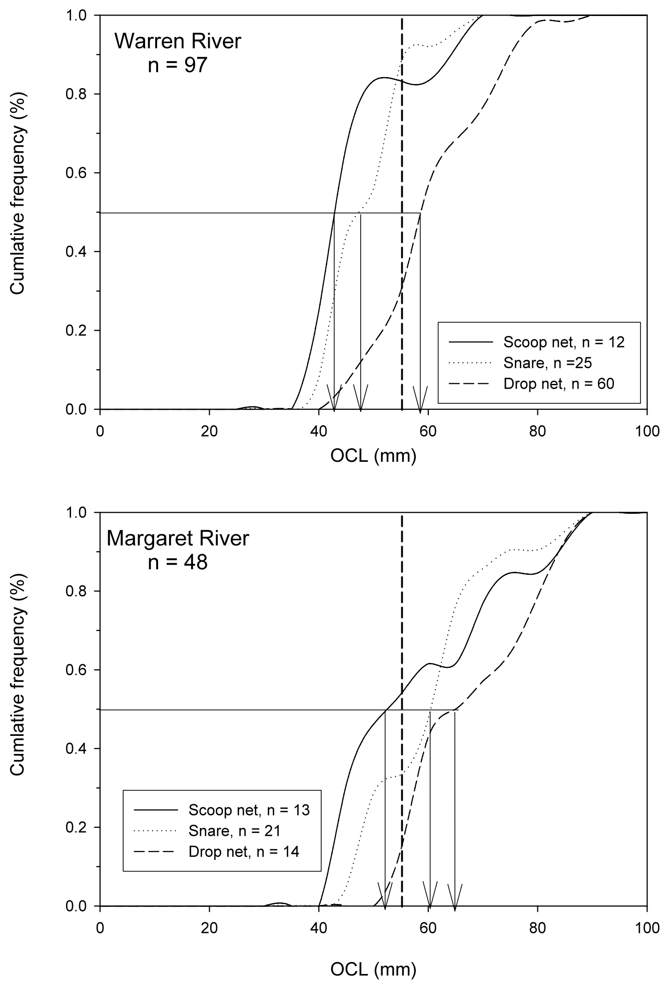

Figure 3a. Cumulative frequency distributions of marron captured from the Warren River (upper figure) and Margaret River (lower figure) sites by all three gears. Vertical dotted line indicates the approximate minimum legal size (55.5 mm OCL). Arrows indicate the OCL of 50% recruitment of marron to each of the gear types.

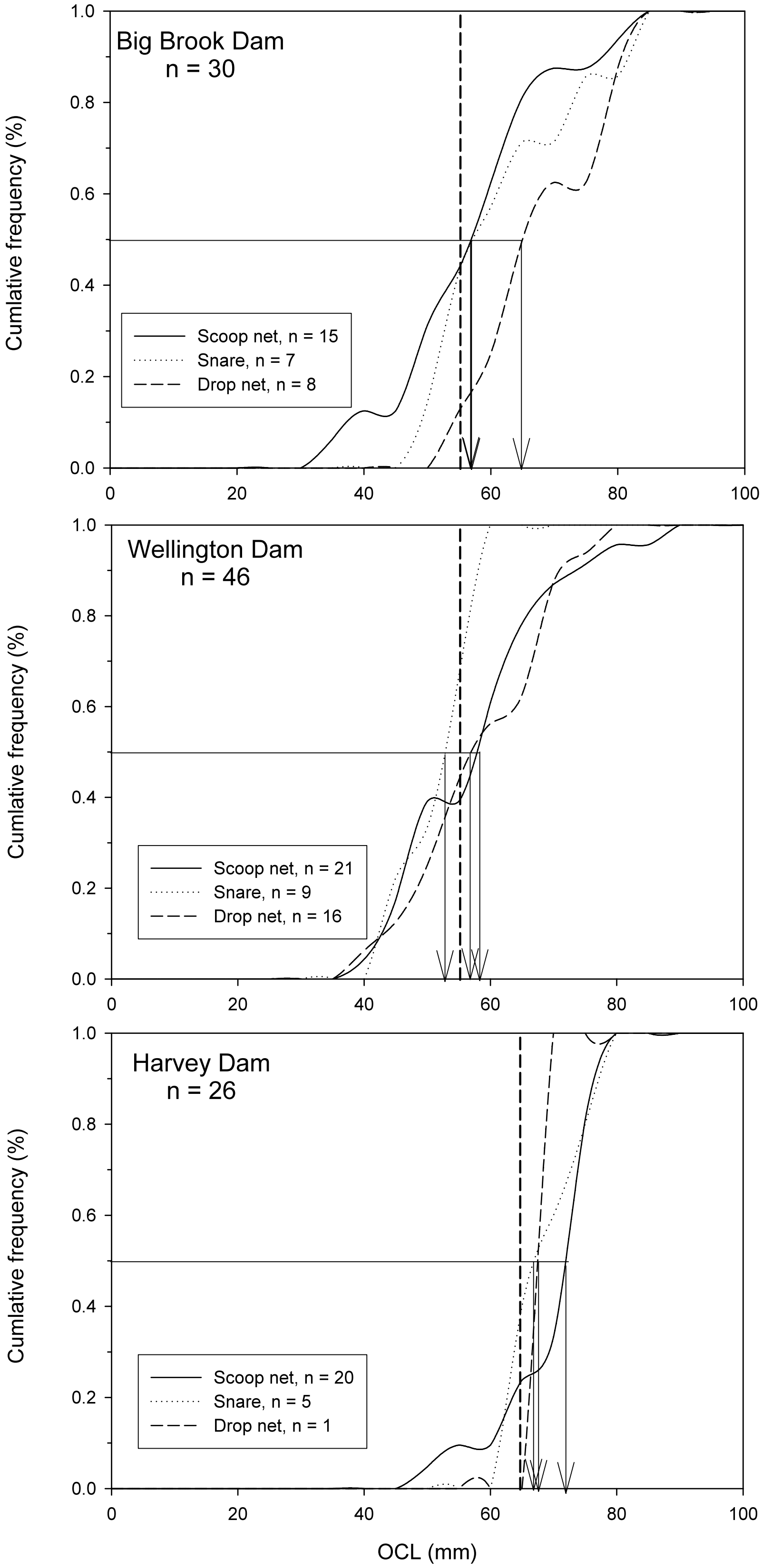

Figure 3b. Cumulative frequency distributions of marron captured from the Big Brook Dam (upper figure), Wellington Dam (middle figure) and Harvey Dam (lower figure) sites by all three gears. Vertical dotted line indicates the approximate minimum legal size (55.5 mm OCL), expect for Harvey Dam where the minimum legal size if 65 mm OCL. Arrows indicate the OCL of 50% recruitment of marron to each of the gear types.

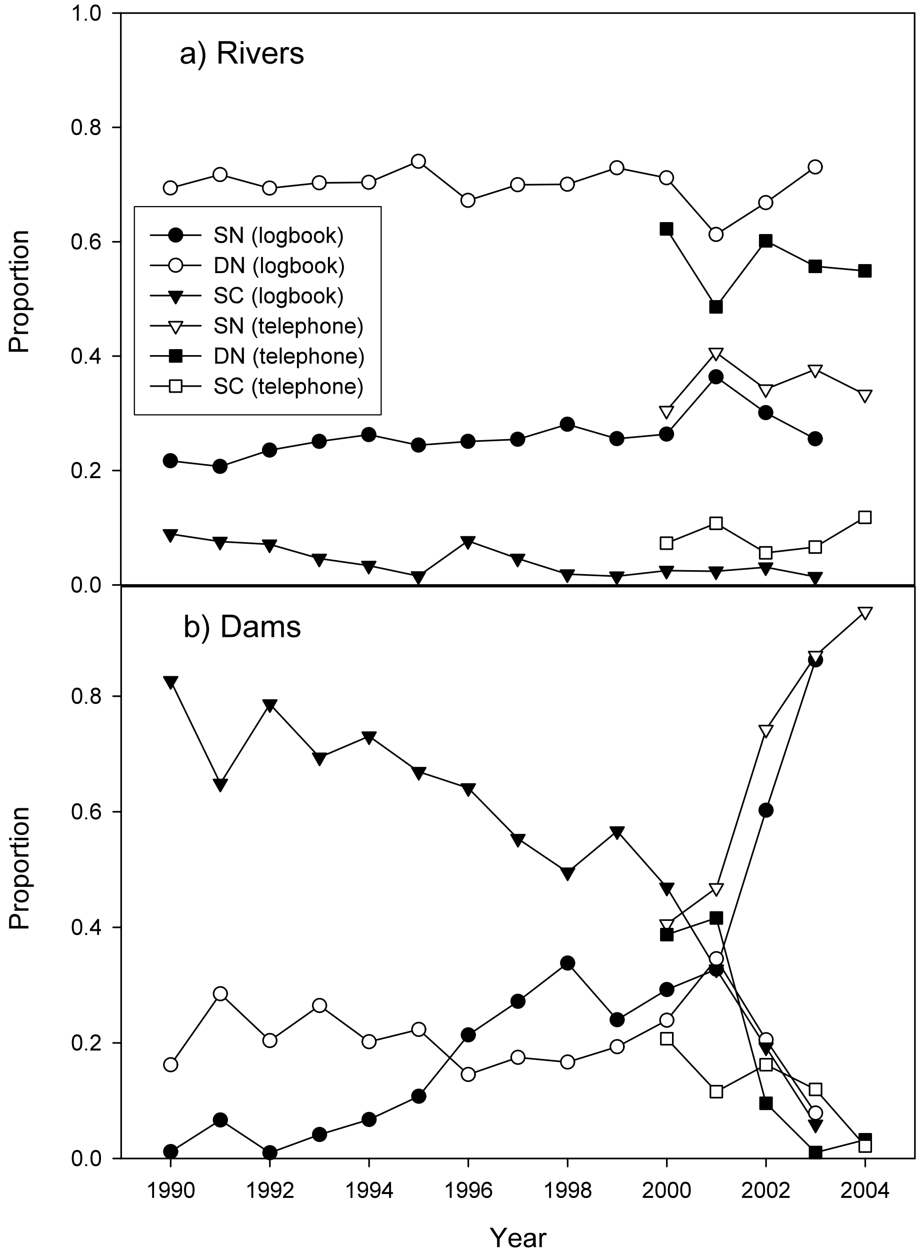

Figure 4. Estimates of the proportional use of gear types in a) rivers and b) dams from logbook and telephone data.

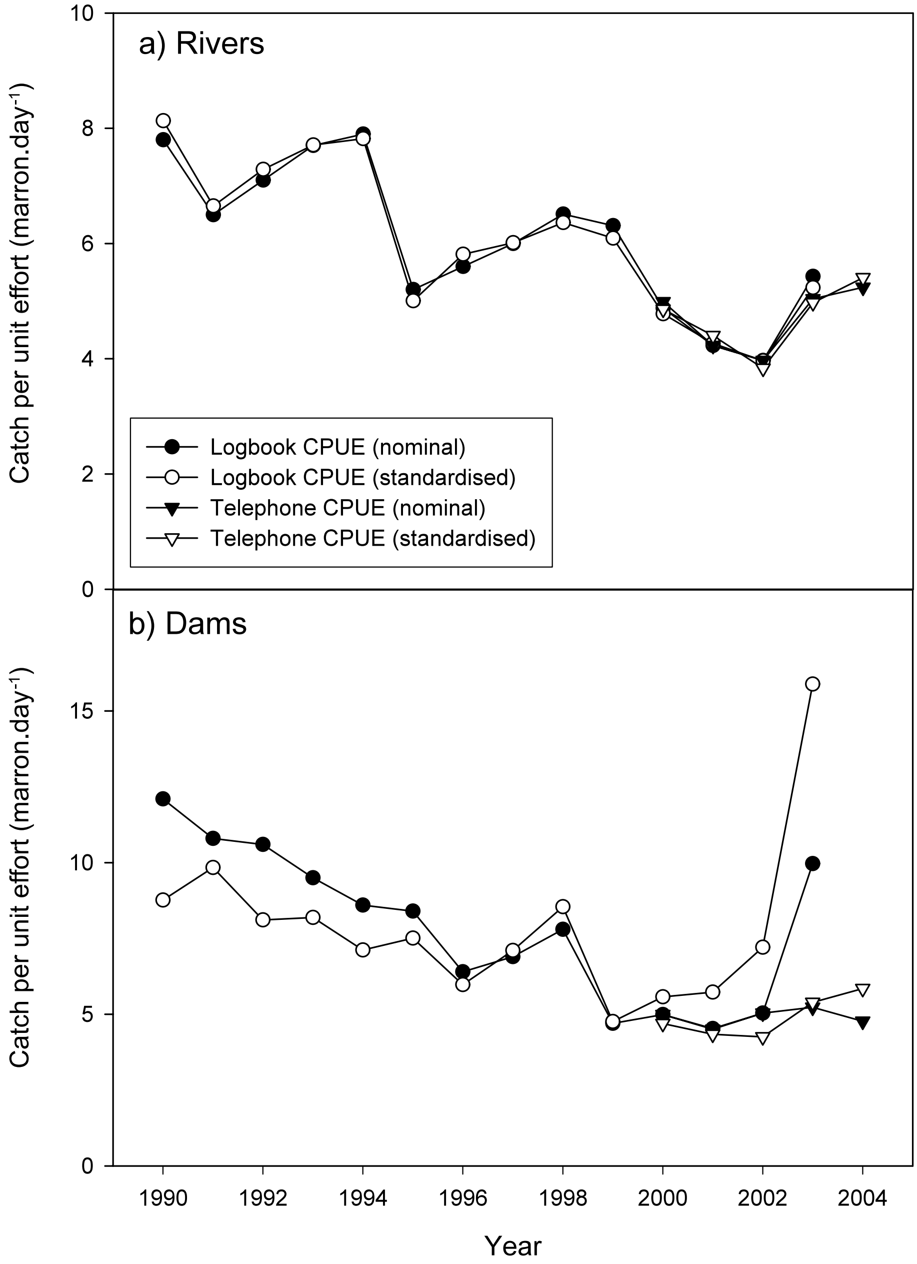

Figure 5. Nominal and standardised estimates of catch per unit effort for a) Rivers and b) Dams from logbook and telephone data, 1990–2004.

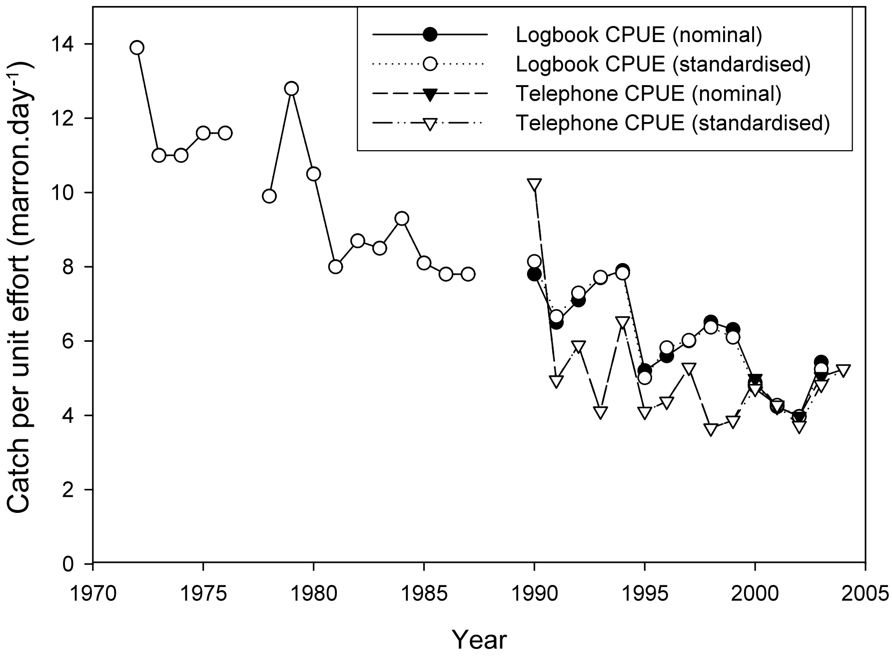

Figure 6. Nominal and standardised estimates of catch per unit effort for rivers from logbook and telephone data since 1971, the entire time-series of data. No logbook data was collected in 1975. A closed season occurred in 1988 and 1989. The nominal and standardised data are virtually identical between 1971 and 1990.

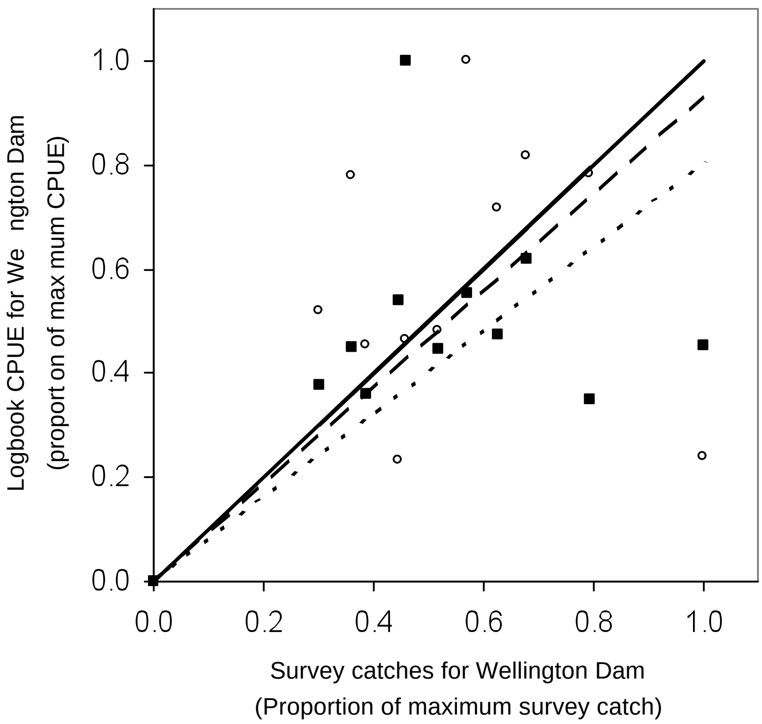

Figure 7. Standardised catches of marron from pre-season research surveys from Wellington Dam against nominal and normalised logbook CPUE data (open circles and dotted line) and standardised and normalised logbook CPUE (black squares and dashed line) for Wellington dam, 1990–2003. Solid line indicates relationship if CPUE was proportional to survey abundance (i.e. slope= 1.0). The large proportion of points below the line of equality suggests hyperdepletion of marron by the recreational fishing. Nominal logbook CPUE series, slope= 0.81; Standardised logbook CPUE series, slope= 0.94.

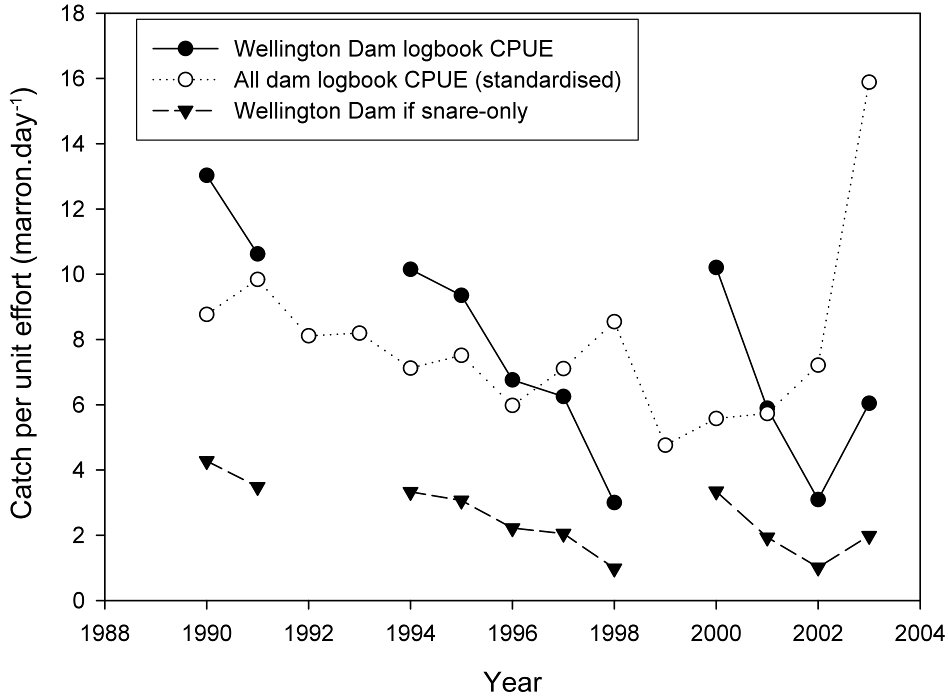

Figure 8. Logbook CPUE for total dams (standardised) and Wellington Dam between 1990 and 2003. The estimated CPUE for Wellington Dam if all effort was undertaken by snares only is also plotted. Wellington was legislated a snare-only marron water in at the start of the 1996 recreational marron fishery season.

3.0 Assessing the influence of key environmental variables on the fishery performance of the recreational crayfish fishery for marron (*Cherax cainii*) in southwestern Australia

Molony B, Bird C, Nguyen V and Beatty S.

3.1 Introduction

Freshwater systems, and the plants and animals within them, are impacted by environmental variables. In particular, freshwater systems are most susceptible to changes in water regime (e.g. rainfall patterns, diversion or extraction of water, construction of dams) (Molony et al. 2002). Molony et al. (2003) demonstrated that recreational catches of marron across the entire fishery in southwestern Australia were broadly correlated to relative rainfall in the previous year, since at least 1990 (Fig. 1). The relationship accounted for almost 20% of the variation in total annual catches throughout the Recreational Marron Fishery since 1990 ($r^2 = 0.197$).

There are a number of ways in which freshwater input is likely to influence aquatic populations through processes such as growth, recruitment, predation and survival (Drinkwater and Frank 1994, Gillanders and Kingsford 2002, Whitfield 2005). Marron populations are likely to be influenced through similar processes.

Firstly, freshwater input, via rainfall and run-off, is responsible for the supply of energy and nutrients (e.g. via the input of leaf litter) to freshwater systems from terrigenous sources, impacting on primary and secondary productivity of freshwater systems (Aleem 1972, Salen-Picard et al. 2002, Meynecke et al. 2006). High levels of rainfall and run-off (and river flow) are likely to result in high levels of energy into freshwater systems, supporting marron populations. Marron can utilise energy from a wide range of trophic levels (Beatty 2006) therefore years of high rainfall is likely to increase the productivity of marron populations.

Increased productivity of marron populations can result from increases in somatic growth rates, and/or increased energy focused towards reproductive processes (e.g. increased fecundity). Increased somatic growth of marron is likely to result in more legal-sized marron in following Recreational Marron Fishery seasons available for capture; increasing catch rates. Increases in energy towards reproductive processes is likely to lead to increases in the number of eggs produced and subsequently juveniles released, and future recruitment (e.g. Meynecke et al. 2006). Juveniles take at least two to three years to reach 55.5 mm OCL (legal size) in marron aquaculture facilities rivers (eg. Beatty et al. 2005) and are likely to take a similar amount of time to reach legal size in large dams. Thus, increased productivity would result in increased catch rates two to three years after increased input of terrigenous material.

In dams, water input through rainfall and/or river flow may also influence marron distribution, likely through changes in habitat availability (Loneragan and Bunn 1999). For example, increases in space as a result of increased water volume in dams is likely to reduce intra-specific and inter-specific competition as marron are able to spread out (e.g. as reported for freshwater fishes by Meynecke et al. 2006). From marron aquaculture research (Morrissy 1992, Lawrence & Jones 2001), high densities of marron also result in reduced growth rates and increased mortality, especially in habitat limited aquaculture ponds (i.e. with few marron hides, Lawrence et al. 2006). It is likely similar effects will occur in habitat-limited dams (Molony and

Bird 2005). Thus increased rainfall and dam volumes would likely increase the growth rate of adult and juvenile marron, and increase marron survival. Thus increased rainfall may result in increased catch rates in the future.

Additionally, volume may influence predation on marron. For example, higher water volumes allow marron to distribute further, potentially increasing the extent of marron habitat. The increase in availability of suitable habitat may potentially reduce predation from red-fin perch, common in many areas of southwestern Australia (Molony and Bird 2005). Further, as all fishing occurs from the banks, dam fullness (a result of water input) during the short season will also influence the level of interaction with fishers and hence fishing mortality (e.g. the extent of fishable bank, concentration of marron).

The extent of marron habitat may also be influenced by water input into dams via regulating oxygen levels (through mixing of water, reduced temperature and reduced salinity). Oxygen has been shown to be critical in marron survival and growth in aquaculture systems, with many aquaculture ponds fitted with paddle-wheel aerators in southwestern Australia.

The Recreational Marron Fishery operates in 11 catchments in southwestern Australia, covering a linear distance of more than 600 km. Thus rainfall varies greatly among and within catchments in the Recreational Marron Fishery. It is likely that relationships between environmental variables (e.g. rainfall volume) and fishery variables (e.g. catch rates) in the Recreational Marron Fishery may be clearer within a single location (e.g. a sub-catchment) than across the entire fishery. The main objective of this chapter is to explore relationships between readily available environmental variables and the performance of the Recreational Marron Fishery (as indexed by CPUE) to better understand the major factors that influence fishery performance and assess the potential for predicative indicators of the future performance of the Recreational Marron Fishery.

3.2 Methods

Study site

Wellington Dam (33.5˚S, 116˚E, Fig. 2) is the largest dam in southwestern Australia that is open to recreational marron fishing. It was selected as the test site due to the large size of the dam and as more than 50% of total dam effort in the Recreational Marron Fishery has been applied to this single water since the late 1990s (Molony et al. 2003). In addition, other agencies have long-term, detailed records of rainfall at various stations within the sub-catchment (Bureau of Meteorology, BoM), estimates of river flow into Wellington Dam at several gauging stations (Department of Environment/ Waters and Rivers Commission, WA) and fullness of Wellington Dam (Water Corporation, WA). Environmental data from these sources (Appendix 1) were available for the Wellington Dam sub-catchment (Fig. 2). Data were complied from the early 1970s, the commencement of fishery monitoring data for the Recreational Marron Fishery, including Wellington Dam (Morrissy and Fellows 1990).

A range of fishery dependent and fishery-independent variables were also available (Appendix 1). From telephone and log-book surveys, estimates of the average catch per unit effort (CPUE, number of legal-sized marron per fisher per day) were available from 1971/72. CPUE data were used as a measure of fishery performance. Further, from anecdotal logbook data, expected CPUE is a major determinant of whether a fisher will participate in the fishery in a given season (C. Bird, unpublished logbook data). Thus, being able to predict the CPUE may provide managers with an indication of likely effort and catches in future Recreational Marron Fishery seasons.

Estimates of total effort (i.e. number of days of fishing per marron season) and total catch per season from Wellington Dam (estimates of total number of marron captured) were also available, but only since 1990 (i.e. 13 seasons) therefore the time-series of these data were too short to incorporate into all analyses (Meynecke et al. 2006). However, total estimated catches are likely to be an important variable in influencing future catches and CPUE, given the large time between juvenile release and recruitment to the Recreational Marron Fishery (about two-to-three years). Other data from fishery independent surveys, including the proportion of berried females (i.e. those carrying external eggs) and pre-season marron abundance were also available from Wellington Dam, although survey data were not available for all years.

Data sources

Records of dam fullness and volume were selected as close as possible to January 1st each year (i.e. prior to the start of the Recreational Marron Fishery season). Dam fullness (% of total fullness) and surface area (% of full surface area) were calculated from data supplied by Water Corporation. Fullness provides volume information and therefore may index the space available for marron. In addition, dam volume may provide an index of the water quality of the dam, as higher volumes may maintain salinity levels below that which are critical to marron growth and survival (<6 ‰, Morrissey 1974). Surface area may provide a proxy measure for the amount of bank available for marron feeding and for access by fishers (all marron fishing occurs from banks).

Rainfall data and stream gauging data were supplied by the Bureau of Meteorology and the Waters and Rivers Commission. Total annual rainfall and total annual river gauging volume were calculated for stations in the catchment above Wellington Dam.

Estimates of total effort and catch-per-unit-effort (CPUE) for each season were obtained from telephone surveys conducted by the Department of Fisheries (Molony et al. 2003). CPUE data for the season following the year for which environmental data were collected (defined as CPUE) were used in the analyses. CPUE data were also lagged by one year (i.e. CPUE+1) as just-undersized marron not retained by fishers are likely to grow into legal size by the following season). CPUE data lagged by two years (i.e. CPUE+2) and three years (i.e. CPUE+3) were also included in analyses, to allow for juveniles produced late in the year of the environmental data (from berried females in pre-season surveys) to grow to the size of recruitment (55.5 mm OCL) into the Recreational Marron Fishery. Each variable was normalised prior to analysis as required (Appendix 2).

Data analysis

Principal Component Analyses (PCA) were undertaken on the complete data set in order to identify overall relationships among variables and potentially reduce the number of variables considered. This was achieved by examining the factor loadings of each variable on major principal component axes. PCAs were also used to examine the relationships between lagged CPUE data and environmental variables (Fig. 3). CPUE lagged by one-year (CPUE+1) or two years (CPUE+2) may provide an index of the influence of environmental variables on the growth rate of marron in the following season. CPUE lagged by three-years (CPUE+3) may provide an index of the impact of environmental variables on the production and survival of juvenile marron released late in the year of the environmental data, as it at least 2 years for marron to grow to a adequate size to recruit the recreational fishery (approximately 55.5 mm OCL, Beatty et al. 2004, Chapter 5).

Subsequent to PCA, generalised linear models (GLMs) were used to examine relationships between CPUE variables and the reduced number of influential environmental variables identified from PCAs. The significance of each GLM and individual variables were examined to determine the amount of variation in CPUE explained within each model (co-efficient of determination, r^2) and the significance of the model (p-values). Adjusted r^2 values were also examined to determine the sensitivity of each model to the removal of a single data point, providing a measure of robustness of each model. Desirability plots were subsequently examined for each GLM, in order to explore the relationship between each independent variable and the CPUE variable being modelled (StatSoft Inc. 2004).

3.3 Results

Although more than 35 separate PCAs were undertaken using either raw or normalised data for each variable, each PCA identified five PC-axes which accounted for more than 90% of the variance in the multi-variate dataset, with the weighting of each variable on each axis similar in all analyses (Appendix 3). There was a high correlation among the total annual rainfall of each rainfall station in the catchment and among gauging station data. This was expected as rainfall volumes, and gauging station river flows are likely to be relatively similar within a sub-catchment. As a result, only the closet rainfall station (Collie) and gauging station (Collie River) were used in further analyses. In addition, only the dam fullness in January (the start of each Recreational Marron Fishery season) was included. Dam volume is likely to be a proxy measure for the accessibility of fishers to the edge of the water (legislation requires that all marron fishing must occur from dam or river banks). A PCA on the reduced data set identified four axes that accounted for approximately 86% of variation in the dataset (Table 1), each with an eigenvalue greater than 0.7 (Fig. 4). These four axes were subsequently examined in more detail.

The first axis (PCA 1) explained more than 38.5% of the variation in the dataset and was composed of rainfall, river flow and CPUE (Table 1, Appendix 4). PCA 2 explained approximately 24.5% of the variation in the dataset and was composed of rainfall and CPUE+1. The third axis was composed mainly of dam fullness in January and CPUE+3, and explained approximately 13.6% of variation. CPUE+2 comprised most of the fourth axis, accounting for almost 10.2% of the variation in the dataset. The four major axes can be described as water input and current CPUE, rainfall and short-term catch rates, dam fullness and long-term catch rates, and mid-term catch rates.

CPUE and environmental variables

Relationships between each catch rate variables (CPUE, CPUE+1, CPUE+2 and CPUE+3) and each environmental variable identified in the first four PCA axes were examined (Fig. 5), using raw and transformed data. Dam fullness appeared to show a clear relationship with catch rate variables. For example, catch rates tended to decline after years when dam fullness in January was less than approximately 60% (or less than 0.6 when fullness data was arcsin transformed). No obvious correlations appeared to exist between the catch rate variables and other environmental variables. However, catch rate variables have shown a steady decline since the early 1980s and thus there is little contrast in the catch rate data.

Generalised linear models (GLMs) were used to further examine the amount of variation in all three CPUE variables explained by environmental variables that contributed the first-four PCA axes. All variables were parameterised using second-order polynomials in the GLMs.

A GLM including annual rainfall from the Collie station, volume of water from the Collie River gauging station and the dam fullness in January explained virtually no variation (approximately 9%) in CPUE between 1973 and 2004; the model was strongly non-significant ($p=0.917$) (Table 2).

No significant relationship was identified between the three environmental variables and CPUE+1 ($p=0.573$) (Table 3). However, a significant model ($r^2 = 0.622$, $p=0.020$) resulted when CPUE was included from the previous year (Table 4). Most of the significance in the model was due to relationships between CPUE and river flow, and between CPUE and CPUE+1 (Table 4, Fig. 6). The river flow data suggested that high flows (more than ln(11) or approximately 60,000 ML) or low flows (less than ln(9) or approximately 8,000 ML) resulted in lower than average catch rates. However, this only influenced CPUE below the mean of ~10 marron per person, per day. The relationship with CPUE+1 suggested that catch rates are likely to be similar between adjacent Recreational Marron Fishery seasons. Rainfall was not a significant factor at $\alpha = 0.05$, although the trend indicated that high or low rainfall resulted in high CPUE; average rainfall produced average catch rates.

The three environmental variables also resulted in a significant model ($p=0.029$) explaining more than 50% of the variation in CPUE+2 (Table 5, Fig. 7). The significance was largely due to the relationship with river flow. In contrast to the relationship with CPUE+1, high CPUE+2 were recorded after high or low flow events. The inclusion of CPUE improved the fit of the model ($r^2 = 0.573$) but reduced the significance ($p=0.058$) (Table 6). However river flow was still the most influential variable, with a similar response of CPUE+2 predicted (Fig. 8).

The three environmental variables accounted for approximately 56% of variability in CPUE+3 ($p=0.017$) (Table 7). Most of the effects were due to river flow and fullness variables, suggesting high or low river flows and high (arsin of more than 1.1 or 80%), or low dam fullness (arsin of less than 0.6 or 60%) in January, produced relatively high catch rates three years later (Fig. 9). Including CPUE slightly improved the model fit ($r^2 = 0.589$, $p=0.068$) (Table 8) with high catch rates again predicted three years after high or low river flows or levels of dam fullness (Fig. 10). Thus low or high flows appear to produce higher than average long-term CPUEs, but not the CPUE of the season immediately following the flow.

3.4 Discussion

Catch rates of marron in Wellington Dam had broad relationships with rainfall, water flow in rivers that feed into the Dam and Dam fullness. Together with CPUE data, a PCA indicated that more than 86% of variation could be explained by relatively few variables (rainfall, river flow and dam fullness), highlighting the major role that these environmental variables have on regulating catch rates of marron populations. This is not surprising given the critical role that water has on marron populations and populations of all freshwater organisms.

GLM analyses using environmental variables and CPUE accounted for more than 60% of variation in CPUE+1 in Wellington Dam (Table 4). The model suggested that CPUE+1 would be highest (i.e. approximately the long-term average) two seasons after median river flows into the dam (approximately 22,000 ML per year in the Collie River). However, the response of the river flow variable peaked at an average level of CPUE+1 (approximately 10 marron per day). The response suggests that high or low river flows reduce CPUE+1, possibly through limitation of energy inputs and space, leading to increased competition (during low flows) and disturbance and/or increased fishing effort (during high flows) during the previous season (i.e. higher CPUE).

Additionally, CPUE+1 would be higher after years of high CPUE (i.e. catch rates between adjacent years were likely to be similar). However, the response of CPUE in relation to flow peaked at approximately 10 per person per day, similar to the daily bag limit imposed on Wellington Dam (and other areas) since 1995. The maximum daily bag limit has been 10 marron per person per day in Wellington Dam since 1995. Thus the CPUE variable may not be as useful a predictor in the contemporary fishery.

Significant effects of river flow were also identified for future catch rates (CPUE+2 and CPUE+3), with the effect of river flow similar for both catch rate variables. Both GLMs suggested that catch rates were increased when water flows in the Collie River three years previous were very high (more than approximately 60,000 ML) or very low (less than approximately 8,000 ML). Low flow events (less than approximately 8,000 ML) have occurred more frequently in the Collie river than high flow events (more than approximately 60,000 ML) since 1971 (Fig. 5). Average catch rates resulted when river flow was average. High flow events may result in high input of nutrients and additional habitat for marron, promoting higher growth rates and production and survival of juveniles. Given the time for juveniles to grow to legal size, the increased future catch rates after years of high flow are likely to be due to higher juvenile production, survival and growth and less total fishing effort (i.e. as marroners may not fish during seasons after very low rainfall) (C. Bird, unpublished logbook data). Low flow periods may also result in higher future catch rates via reducing numbers of marron in the season following the flow event (i.e. CPUE), reducing competition and survival of juveniles produced from adults captured during the CPUE year. This is supported by the better fit (r^2-values) of the GLMS with the incorporation of CPUE into the GLMs modelling CPUE+2 (Table 6) and CPUE+3 (Table 8).

It is clear that water volume is critical to freshwater populations. Thus, it was expected that the analyses undertaken would identify significant models describing the influence of environmental variables on marron CPUEs. However, very few models were significant at $\alpha = 0.05$. There are several potential reasons why most GLMs were non-significant. Firstly, the annual series of data were relatively short (less than 30 data points (years) of consecutive data) and may show little contrast in the variables. Typically, time-series of data should be greater than 50 consecutive points (Meynecke et al. 2006). Additionally, fishery data from the Recreational Marron Fishery is collected over a relatively short period in each year (the season has been less than 60 days long since 1990 and less than 20 days long since 2003). As a result, all fishery data, and subsequently environmental data used in this project, were annualised reducing the contrast and information available from each variable. With the use of lagged CPUE data, the time series were further reduced (by between one and three years).

However, the small size of the contemporary Recreational Marron Fishery is unlikely to result in additional data (e.g. other variables) or higher resolution data (e.g. estimates of catch rates on a finer temporal scale) being collected in the future. Given the relatively short time series and expected low power of the GLMs, the results of the models may be interpreted using a higher α-level. Using an α of 0.10 or higher to interpret the GLMs results in additional models becoming significant.

Finally, other variables (e.g. concentration of chlorophyll-a, carbon levels, input of leaf litter) could be used, although the collection of this data involves much greater effort and costs to obtain than data freely available from other government agencies. However, the lack of understanding of the role of the variables used can lead to erroneous modelling outcomes in more complicated models (Meynecke et al. 2006). This is especially applicable to the Recreational Marron Fishery given the lack of previous modelling of the effects of environmental variables on catch rates and biological processes (e.g. growth rates and reproduction).

Nonetheless, one variable that was further explored was total catch from the previous season. Given the biology of marron, removing large numbers of legal-sized marron is likely to impact on future catches (e.g. high catches in previous seasons may deplete populations of marron, which would potentially impact on future catch rates; reduced number of marron may result in reduced intra-specific competition thereby potentially increasing juvenile survival and growth rates of remaining marron). Estimates of total annual catches from Wellington Dam were only available since 1990 and thus the time-series was relatively short. However, the addition of catches into the models resulted in GLMs explaining more than 60% of variation in catch rate variables (Tables 9, 10, 11 and 12). Though, no model was significant, most likely due to the short time series. Nonetheless, the responses of the catch variable suggested depletion at high levels of previous catch (Fig. 11). That is, relatively high catches in the previous season (> 50,000 marron) were associated with high catch rates in the following, supporting previous modelling which suggested that catch rates tended to be similar between adjacent years. However, depletion effects were identified with catch rates declining when catches exceeded approximately 70,000 marron (Fig. 11). This is likely to be due to large catches resulting in virtually all legal-sized marron being removed, with few being available in following seasons to be captured or to reproduce. However, the effects of all variables in these shortened time-series were likely to be poorly estimated and uncertain. Further, an annual catch of more than 70,000 marron per season has only been reported in two Recreational Marron Fishery seasons since 1990. Additionally, the reduced season applied since 2003 is unlikely to result in catches of this magnitude in the future.

Nonetheless, by using the outputs of the GLMs as indicative models rather than predictive models, the use of three, easily obtainable environmental variables explained up to 60% of variation in CPUE up to three Recreational Marron Fishery seasons in the future (Table 13). The GLMs may be interpreted as a broad index of the likely CPUEs (and therefore abundances) of marron in future years.

Are relationships between CPUE and environmental variables likely to be similar in other locations within the Recreational Marron Fishery? It is likely that similar effects will be reported in other dam sites within the Recreational Marron Fishery. However, the results may not be as applicable to river sites due to the complex and variable nature of rivers compared to dam sites. However, as many rivers in southwestern Australia tend to break into pools during summer, around the time of the annual Recreational Marron Fishery, the regulatory effects of rainfall may be similar (may not break into pools during summer in higher than average rainfall years though). However, there is the potential for regional differences in rainfall-catch relationships, at least for some species of fish (Meynecke et al. 2006). Further, relationships may be impacted by variations in fishing effort (da Silva 1986) depending on exploitation levels of the fishery (Vance et al. 1985). In the Recreational Marron Fishery, variations in effort may result from differential rainfall patterns across the fishery, and the recent closures of some areas by water managers, resulting in higher levels of effort in the remaining open areas (e.g. Wellington Dam). Thus, relationships may be even stronger at individual sites (e.g. specific areas within dams), especially given the limited dispersal and range of marron (Chapter 1).

3.5 Management implications

1. Easily obtainable environmental data, as used in this study, may be used to provide advice on catch rates in future years. Thus managers may be able to consider management options based on these relationships, assuming for example, that most or all fishers, will achieve

their bag limit or recent average bags. These management options can be applied and tested by continued monitoring of the fishery (i.e. adaptive management).

2. River flow and dam volume have a high degree of influence on catch rates in the Recreational Marron Fishery. These variables are beyond the management control of the Department of Fisheries. However, river flow and dam fullness may be regulated, albeit by other government agencies. For example, the Water Corporation regulates water releases from Wellington Dam while the Waters & Rivers Commission (Department of Water) issue licences to extract water from rivers. These variables explain a large amount of variation in marron catch rates (up to 60%) on Recreational Marron Fishery catch rates since the early 1970s. Thus, the results of this study may open dialogue between the Department of Fisheries and water managers, to encourage water managers to consider recreational fishing opportunities.

3. Climatic modelling by the CSIRO has indicated that southwestern Australia is likely to receive significantly less total rainfall, and less winter rainfall in the future (Whetton et al. 2005). Recreational managers and scientists may use this information to examine future scenarios of the marron fishery under these rainfall predictions.

3.6 References

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Table 1. Summary results of final PCA analyses on Wellington Dam sub-catchment and Recreational Marron Fishery data, 1973–2004.

Principal Component Axis	1	2	3	4
Major variable(s) contributing to the Axis	River flow, rainfall , CPUE	Rainfall, CPUE+1	Dam fullness, CPUE+3	CPUE+2
Amount of variance in the data explained by the axis	38.5%	24.5%	13.6 %	10.3 %
Cumulative variance	38.5%	63.1%	76.7%	86.8%

Table 2. Summary of the GLM data modelling CPUE and environmental variables of total annual rainfall in Collie, natural log of the total annual river flow of the Collie River and the arcsin fullness of Wellington Dam at the start of the year.

Table 2a. Summary of the significance of the GLM

	Multiple R^2	Adjusted R^2	SS	df	MS	SS residual	Df residual	MS residual	F	p
CPUE+1	0.0925	0.038	143.632	6	23.939	1533.761	19	74.125	0.323	0.917

Table 2b. Summary of the significance of the each variable in the GLM. All variables were parameterised using a second order polynomial. The natural log of gauging data and the arcsin value of dam fullness were used in the analyses.

	SS	df	MS	F	p
Intercept	26.373	1	26.373	0.356	0.558
Collie annual rainfall	10.626	1	10.626	0.143	0.709
Collie annual rainfall^2	7.222	1	7.222	0.097	0.758
Collie River annual flow	22.854	1	22.854	0.308	0.585
Collie River annual flow^2	17.965	1	17.965	0.242	0.628
Dam fullness	0.518	1	0.518	0.007	0.934
Dam fullness^2	0.937	1	0.937	0.013	0.912
Error	1408.380	19	74.125		

Table 3. Summary of the GLM data modelling CPUE+1 and environmental variables of total annual rainfall in Collie, natural log of the total annual river flow of the Collie River and the arcsin fullness of Wellington Dam at the start of the year.

Table 3a. Summary of the significance of the GLM.

	Multiple R^2	Adjusted R^2	SS	df	MS	SS residual	Df residual	MS residual	F	p
CPUE+1	0.204	0.002	342.570	6	57.095	1333.595	19	70.189	0.813	0.573

Table 3b. Summary of the significance of the each variable in the GLM. All variables were parameterised using a second order polynomial. The natural log of gauging data and the arcsin value of dam fullness were used in the analyses.

	SS	df	MS	F	p
Intercept	20.378	1	20.378	0.290	0.596
Collie annual rainfall	1.471	1	1.471	0.021	0.886
Collie annual rainfall^2	3.844	1	3.844	0.055	0.817
Collie River annual flow	17.227	1	17.227	0.245	0.626
Collie River annual flow^2	13.431	1	13.431	0.191	0.667
Dam fullness	0.381	1	0.381	0.005	0.942
Dam fullness^2	0.480	1	0.480	0.007	0.935
Error	1333.595	19	70.189		

Table 4. Summary of the GLM data modelling CPUE+1 with CPUE and environmental variables of total annual rainfall in Collie, natural log of the total annual river flow of the Collie River and the arcsin fullness of Wellington Dam at the start of the year.

Table 4a. Summary of the significance of the GLM.

	Multiple R^2	Adjusted R^2	SS	df	MS	SS residual	Df residual	MS residual	F	p
CPUE+1	0.622	0.187	586.236	8	73.280	356.202	16	22.263	3.292	0.020

Table 4b. Summary of the significance of the each variable in the GLM. All variables were parameterised using a second order polynomial.

	SS	df	MS	F	p
Intercept	88.371	1	88.3713	3.969	0.064
Collie annual rainfall	45.890	1	45.890	2.061	0.170
Collie annual rainfall^2	43.101	1	43.101	1.936	0.183
CPUE	97.224	1	97.223	4.367	0.053
CPUE^2	1.989	1	1.989	0.089	0.769
Collie River annual flow	98.515	1	98.515	4.425	0.052
Collie River annual flow^2	92.253	1	92.253	4.144	0.059
Dam fullness	0.228	1	0.228	0.010	0.921
Dam fullness^2	0.325	1	0.325	0.015	0.905
Error	356.202	16	22.263		

Table 5. Summary of the GLM data modelling CPUE+2 with environmental variables of total annual rainfall in Collie, natural log of the total annual river flow of the Collie River and the arcsin fullness of Wellington Dam at the start of the year.

Table 5a. Summary of the significance of the GLM.

	Multiple R^2	Adjusted R^2	SS	df	MS	SS residual	Df residual	MS residual	F	p
CPUE+2	0.508	0.118	843.244	6	140.541	815.489	18	45.305	3.102	0.029

Table 5b. Summary of the significance of the each variable in the GLM. All variables were parameterised using a second order polynomial.

	SS	df	MS	F	p
Intercept	137.209	1	137.209	3.029	0.099
Collie annual rainfall	26.089	1	26.089	0.576	0.458
Collie annual rainfall^2	33.203	1	33.203	0.733	0.403
Collie River annual flow	130.866	1	130.866	2.889	0.106
Collie River annual flow^2	119.385	1	119.385	2.635	0.122
Dam fullness	27.631	1	27.631	0.610	0.445
Dam fullness^2	38.147	1	38.147	0.842	0.371
Error	1333.595	19	70.189		

Table 6. Summary of the GLM data modelling CPUE+2 with CPUE and environmental variables of total annual rainfall in Collie, natural log of the total annual river flow of the Collie River and the arcsin fullness of Wellington Dam at the start of the year.

Table 6a. Summary of the significance of the GLM.

	Multiple R^2	Adjusted R^2	SS	df	MS	SS residual	Df residual	MS residual	F	p
CPUE+2	0.573	0.123	861.265	8	107.658	640.713	15	42.714	2.520	0.058

Table 6b. Summary of the significance of the each variable in the GLM. All variables were parameterised using second order polynomials.

	SS	df	MS	F	p
Intercept	89.553	1	89.553	2.097	0.168
Collie annual rainfall	3.209	1	3.209	0.075	0.788
Collie annual rainfall^2	4.737	1	4.737	0.111	0.744
CPUE	13.438	1	13.438	0.315	0.583
CPUE^2	0.427	1	0.427	0.010	0.922
Collie River annual flow	78.263	1	78.263	1.832	0.196
Collie River annual flow^2	68.776	1	68.776	1.610	0.224
Dam fullness	28.443	1	28.443	0.666	0.427
Dam fullness^2	32.152	1	32.152	0.753	0.399
Error	640.713	15	42.714		

Table 7. Summary of the GLM data modelling CPUE+3 with environmental variables of total annual rainfall in Collie, natural log of the total annual river flow of the Collie River and the arcsin fullness of Wellington Dam at the start of the year.

Table 7a. Summary of the significance of the GLM.

	Multiple R^2	Adjusted R^2	SS	df	MS	SS residual	Df residual	MS residual	F	p
CPUE+3	0.5605	0.163	877.165	6	146.194	691.512	17	40.677	3.594	0.017

Table 7b. Summary of the significance of the each variable in the GLM. All variables were parameterised using a second order polynomial.

	SS	df	MS	F	p
Intercept	455.184	1	455.184	11.190	0.004
Collie annual rainfall	127.574	1	127.574	3.136	0.094
Collie annual rainfall^2	137.588	1	137.588	3.382	0.083
Collie River annual flow	357.567	1	357.567	8.790	0.009
Collie River annual flow^2	335.480	1	335.480	8.247	0.011
Dam fullness	306.661	1	306.661	7.539	0.014
Dam fullness^2	272.612	1	272.612	6.702	0.019
Error	691.512	17	40.677		

Table 8. Summary of the GLM data modelling CPUE+3 with CPUE and environmental variables of total annual rainfall in Collie, natural log of the total annual river flow of the Collie River and the arcsin fullness of Wellington Dam at the start of the year.

Table 8a. Summary of the significance of the GLM.

	Multiple R^2	Adjusted R^2	SS	df	MS	SS residual	Df residual	MS residual	F	p
CPUE+3	0.589	0.125	891.192	8	111.399	621.656	14	44.404	2.509	0.063

Table 8b. Summary of the significance of the each variable in the GLM. All variables were parameterised using a second order polynomial.

	SS	df	MS	F	p
Intercept	388.099	1	388.099	8.740	0.010
Collie annual rainfall	81.898	1	81.898	1.844	0.196
Collie annual rainfall^2	84.024	1	84.024	1.892	0.191
CPUE	0.612	1	0.612	0.014	0.908
CPUE^2	3.195	1	3.195	0.072	0.792
Collie River annual flow	294.081	1	294.081	6.623	0.022
Collie River annual flow^2	271.434	1	271.434	6.113	0.027
Dam fullness	297.715	1	297.715	6.705	0.021
Dam fullness^2	277.613	1	277.613	6.252	0.025
Error	621.656	14	44.404		

Table 9. Summary of the GLM data modelling CPUE with environmental variables of total annual rainfall in Collie, natural log of the total annual river flow of the Collie River and the arcsin fullness of Wellington Dam at the start of the year and catches.

Table 9a. Summary of the significance of the GLM.

	Multiple R^2	Adjusted R^2	SS	df	MS	SS residual	Df Residual	MS residual	F	p
CPUE	0.880	0.16	126.735	8	15.842	17.280	2	8.640	1.834	0.400

Table 9b. Summary of the significance of the each variable in the GLM. All variables were parameterised using a second order polynomial.

	SS	df	MS	F	p
Intercept	0.094	1	0.094	0.011	0.926
Collie annual rainfall	0.313	1	0.313	0.036	0.867
Collie annual rainfall^2	0.240	1	0.240	0.028	0.883
Previous season’s catch	19.438	1	19.438	2.250	0.272
Previous season’s catch^2	45.598	1	45.598	5.278	0.148
Collie River annual flow	0.196	1	0.196	0.023	0.894
Collie River annual flow^2	0.166	1	0.166	0.019	0.902
Dam fullness	7.485	1	7.485	0.866	0.450
Dam fullness^2	8.469	1	8.469	0.980	0.426
Error	17.280	2	8.640		

Table 10. Summary of the GLM data modelling CPUE+1 with environmental variables of total annual rainfall in Collie, natural log of the total annual river flow of the Collie River and the arcsin fullness of Wellington Dam at the start of the year and catches.

Table 10a. Summary of the significance of the GLM.

	Multiple R^2	Adjusted R^2	SS	df	MS	SS residual	Df residual	MS residual	F	p
CPUE+1	0.639	0.652	126.342	8	15.793	71.576	2	35.788	0.441	0.834

Table 10b. Summary of the significance of the each variable in the GLM. All variables were parameterised using a second order polynomial.

	SS	df	MS	F	p
Intercept	8.035	1	8.035	0.225	0.682
Collie annual rainfall	26.561	1	26.561	0.742	0.480
Collie annual rainfall^2	25.231	1	25.231	0.705	0.489
Previous season's catch	60.668	1	60.668	1.695	0.323
Previous season's catch^2	72.672	1	72.672	2.030	0.290
Collie River annual flow	11.745	1	11.745	0.328	0.625
Collie River annual flow^2	12.060	1	12.060	0.337	0.620
Dam fullness	2.801	1	2.801	0.078	0.806
Dam fullness^2	1.456	1	1.456	0.041	0.859
Error	71.576	2	35.788		

Table 11. Summary of the GLM data modelling CPUE+2 with environmental variables of total annual rainfall in Collie, natural log of the total annual river flow of the Collie River and the arcsin fullness of Wellington Dam at the start of the year and catches.

Table 11a. Summary of the significance of the GLM.

	Multiple R^2	Adjusted R^2	SS	df	MS	SS residual	Df residual	MS residual	F	p
CPUE+2	0.836	0.033	169.077	8	21.135	33.061	2	16.531	1.279	0.511

Table 11b. Summary of the significance of the each variable in the GLM. All variables were parameterised using a second order polynomial.

	SS	df	MS	F	P
Intercept	23.563	1	23.563	1.425	0.355
Collie annual rainfall	39.555	1	39.555	2.393	0.262
Collie annual rainfall^2	35.791	1	35.791	2.165	0.279
Previous season's catch	2.100	1	2.100	0.127	0.756
Previous season's catch^2	0.003	1	0.003	0.001	0.990
Collie River annual flow	25.876	1	25.876	1.565	0.337
Collie River annual flow^2	25.472	1	25.472	1.541	0.340
Dam fullness	13.353	1	13.353	0.808	0.464
Dam fullness^2	18.585	1	18.585	1.124	0.400
Error	33.061	2	16.531		

Table 12. Summary of the GLM data modelling CPUE+3 with environmental variables of total annual rainfall in Collie, natural log of the total annual river flow of the Collie River and the arcsin fullness of Wellington Dam at the start of the year and catches.

Table 12a. Summary of the significance of the GLM.

	Multiple R^2	Adjusted R^2	SS	df	MS	SS residual	Df residual	MS residual	F	p
CPUE+3	0.863	0.100	176.622	8	22.078	27.939	2	13.970	1.580	0.444

Table 12b. Summary of the significance of the each variable in the GLM. All variables were parameterised using a second order polynomial.

	SS	df	MS	F	p
Intercept	33.968	1	33.968	2.432	0.259
Collie annual rainfall	17.640	1	17.640	1.263	0.378
Collie annual rainfall^2	16.962	1	16.962	1.214	0.385
Previous season's catch	41.170	1	41.170	2.947	0.228
Previous season's catch^2	63.754	1	63.754	4.564	0.166
Collie River annual flow	28.657	1	28.657	2.051	0.288
Collie River annual flow^2	28.001	1	28.001	2.004	0.293
Dam fullness	20.926	1	20.926	1.498	0.346
Dam fullness^2	20.234	1	20.234	1.448	0.352
Error	27.939	2	13.970		

Table 13. Summary of the relationships between CPUE and predictive variables examined in the GLMs. Predictive variables significant at $\alpha > 0.10$. *, significant at $\alpha > 0.20$.

Catch rate variable	Independent variables	Significant variables	R^2	P>F
CPUE	Collie River annual rainfall, Collie River annual flow, dam fullness (January)	No significant model identified		
CPUE + 1	Collie River annual rainfall, Collie River annual flow, dam fullness (January), CPUE	Collie River annual flow, CPUE (previous season)	0.622	0.020
CPUE+2	Collie River annual rainfall, Collie River annual flow, dam fullness (January)	Collie River annual flow	0.508	0.029
	Collie River annual rainfall, Collie River annual flow, dam fullness (January), CPUE	Collie River annual flow*	0.573	0.058
CPUE + 3	Collie River annual rainfall, Collie River annual flow, dam fullness (January)	Collie River annual flow, dam fullness (January)	0.559	0.017
	Collie River annual rainfall, Collie River annual flow, dam fullness (January), CPUE	Collie River annual flow, dam fullness (January)	0.589	0.068

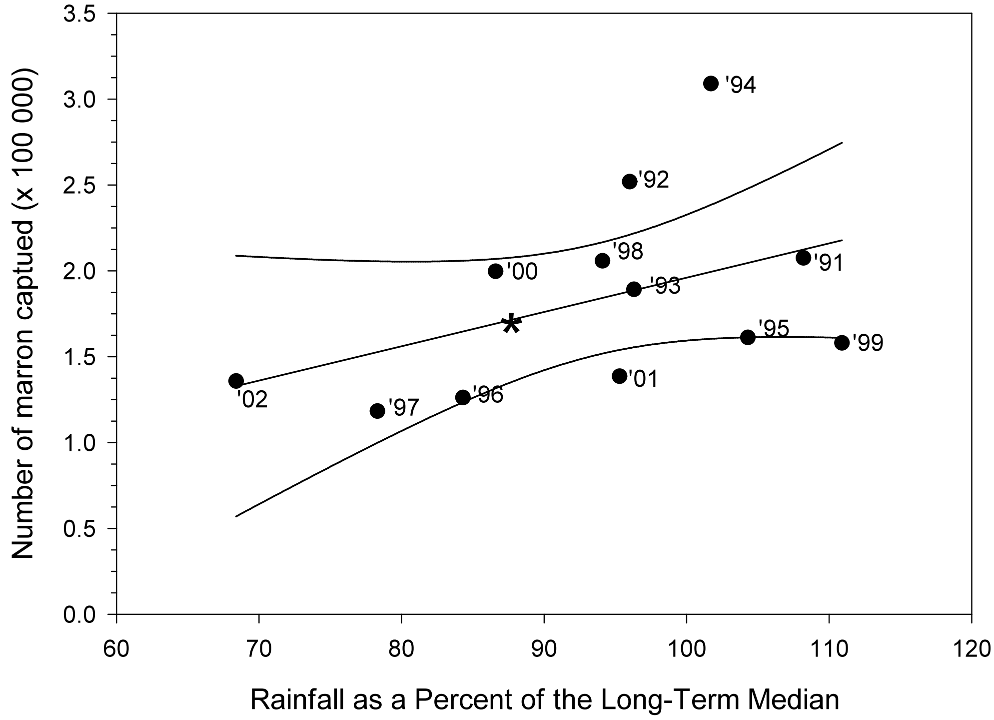


Figure 1. Relationship between relative annual rainfall (January—December) (percent of long-term median rainfall) and total marron catch in the following season. 95% confidence limits are shown around the regression line. Note that the catch and rainfall for 1990 was removed from the analysis due to the abnormally high catch and effort during this season after to two years of closures. (* indicates the predicted catch for the 2003 season). Molony et al. 2003.

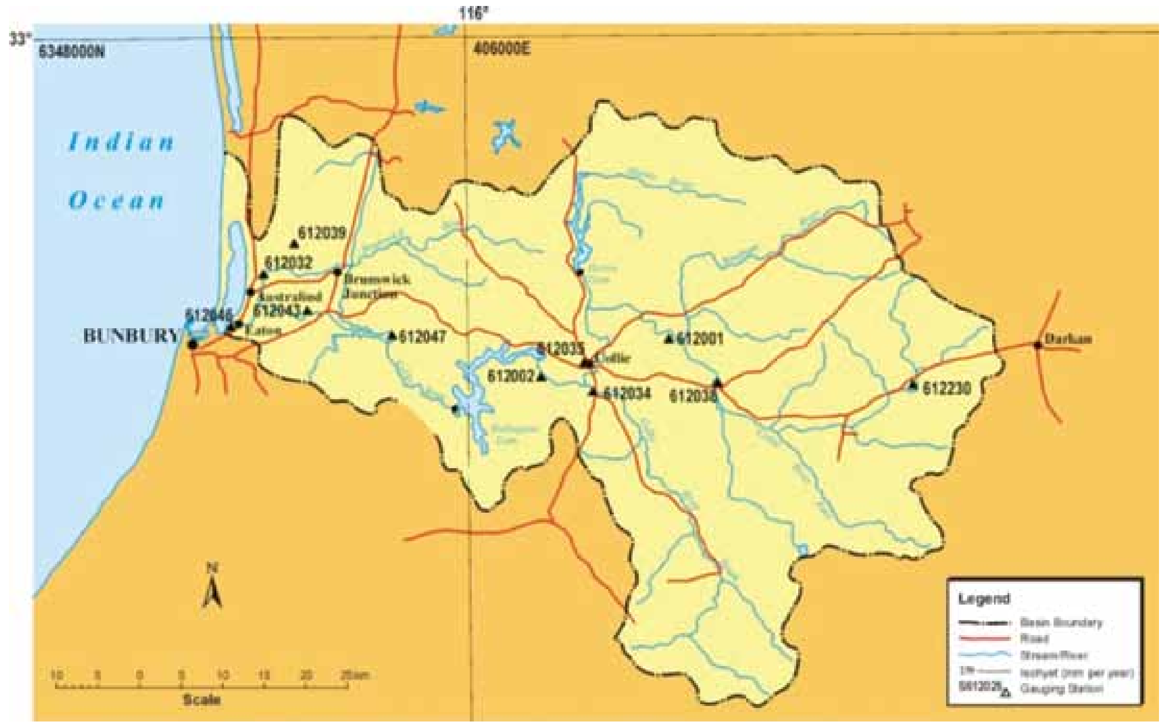


Figure 2. Map of the Collie River catchment and Wellington Dam sub-catchment indicating the position of Wellington Dam, river-flow gauging stations and associated reference numbers (▲) monitored by the Department of Water (DoW) and/or the Bureau of Meteorology (BoM). Figure from of the Department of Water website.

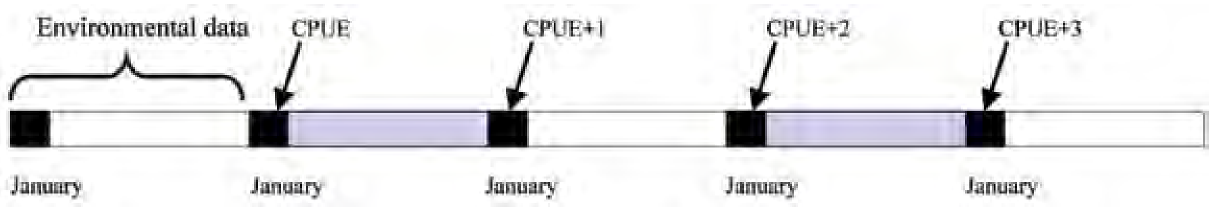


Figure 3. Timing of the collection of environmental data, CPUE and lagged CPUE variables (CPUE+1, CPUE+2, CPUE+3). Black shaded areas indicate the approximate position of the Recreational Marron Fishery season each year (January – February).

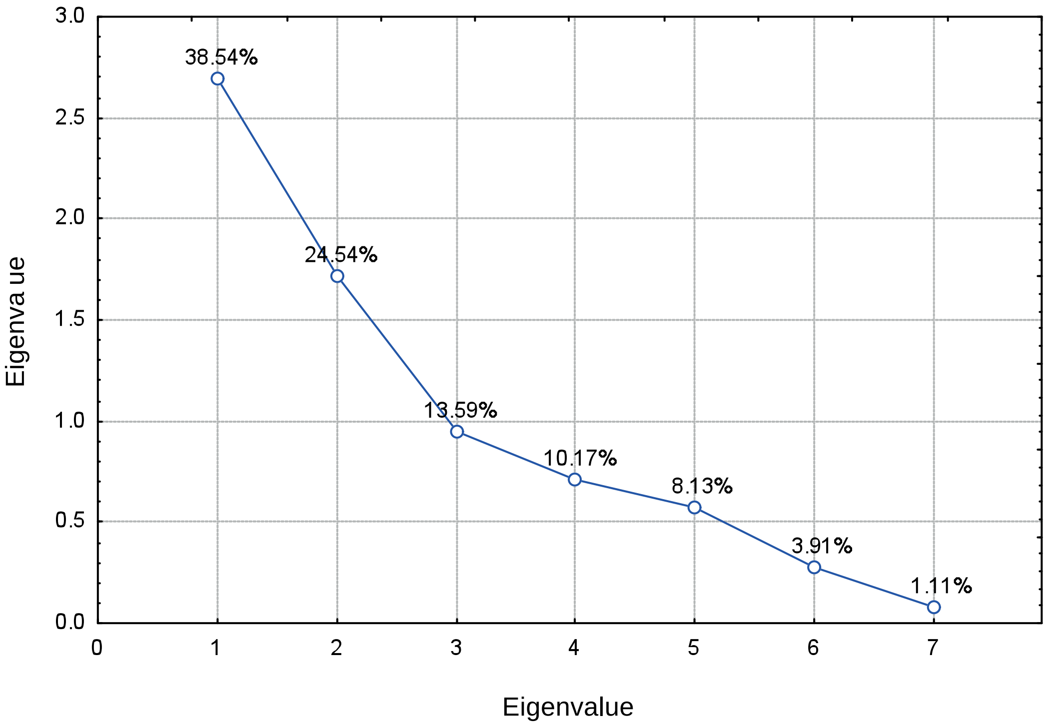


Figure 4. Scree-plot of the final PCA analysis on Wellington Dam sub-catchment and Recreational Marron Fishery data. Axes with eigenvalues greater than 0.7 were examined in more detail. The values above each point represents the percentage of variation in the dataset each axis explains.

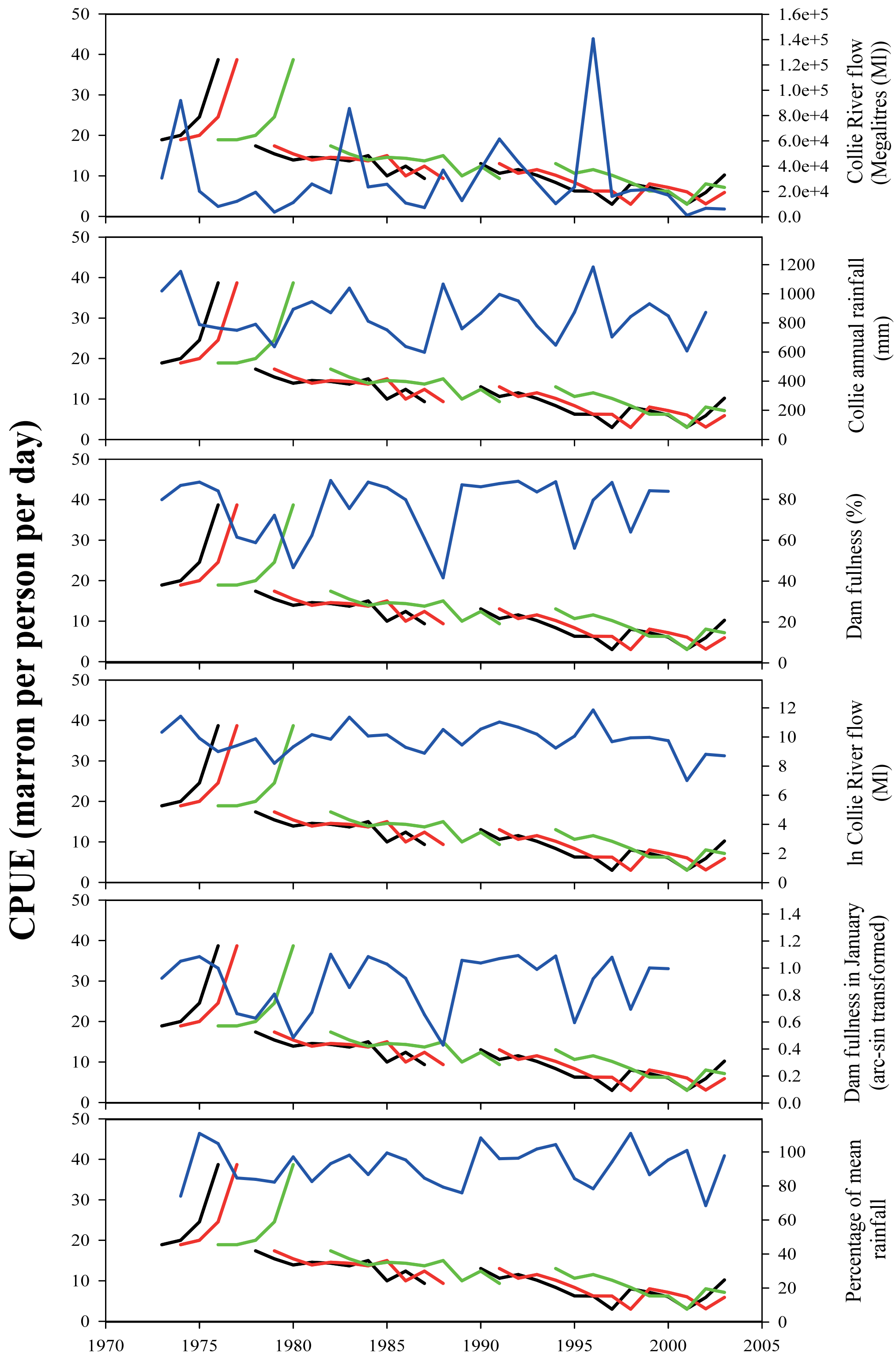


Figure 5. Relationships between catch rate data (CPUE, left hand axes) and environmental variables (blue lines, right hand axes) in the Wellington Dam sub-catchment, 1973–2004. Line colours, black line, CPUE in the same year as the environmental variable (i.e. no lag); red line, CPUE+1; green line, CPUE+3. CPUE+2 not plotted for clarity.

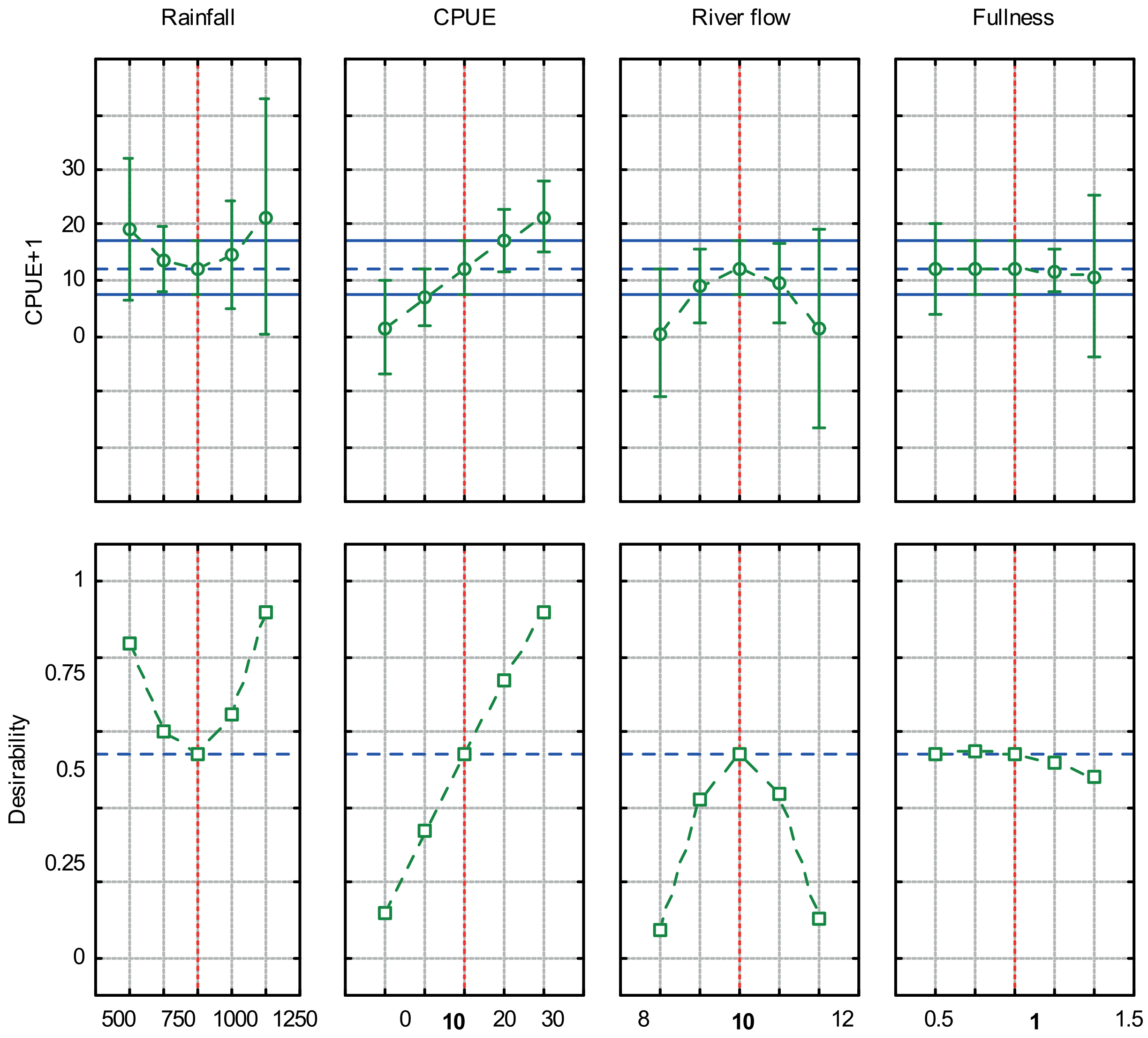


Figure 6. Relationships between CPUE+1 (marron per person per day) and independent variables of annual Collie rainfall ('Rainfall', mm), CPUE (previous season, marron per person per day), annual volume of water flowing down the Collie River into Wellington Dam ('River flow', ML) and fullness of Wellington Dam in January ('Fullness', arcsin percentage). Upper figures, modelled effect of each variable on CPUE+1. Red dotted vertical lines, mean of each predictor variable; blue lines, mean (dotted) and 95% confidence limits (solid lines) for CPUE+1; green error bars, 95% prediction limits of the environmental data for CPUE+1. Lower figures, desirability plots of each predictor variable for CPUE+1 while other independent variables are held constant at the levels indicated by the red vertical lines. Higher desirability levels produce higher CPUE+1.

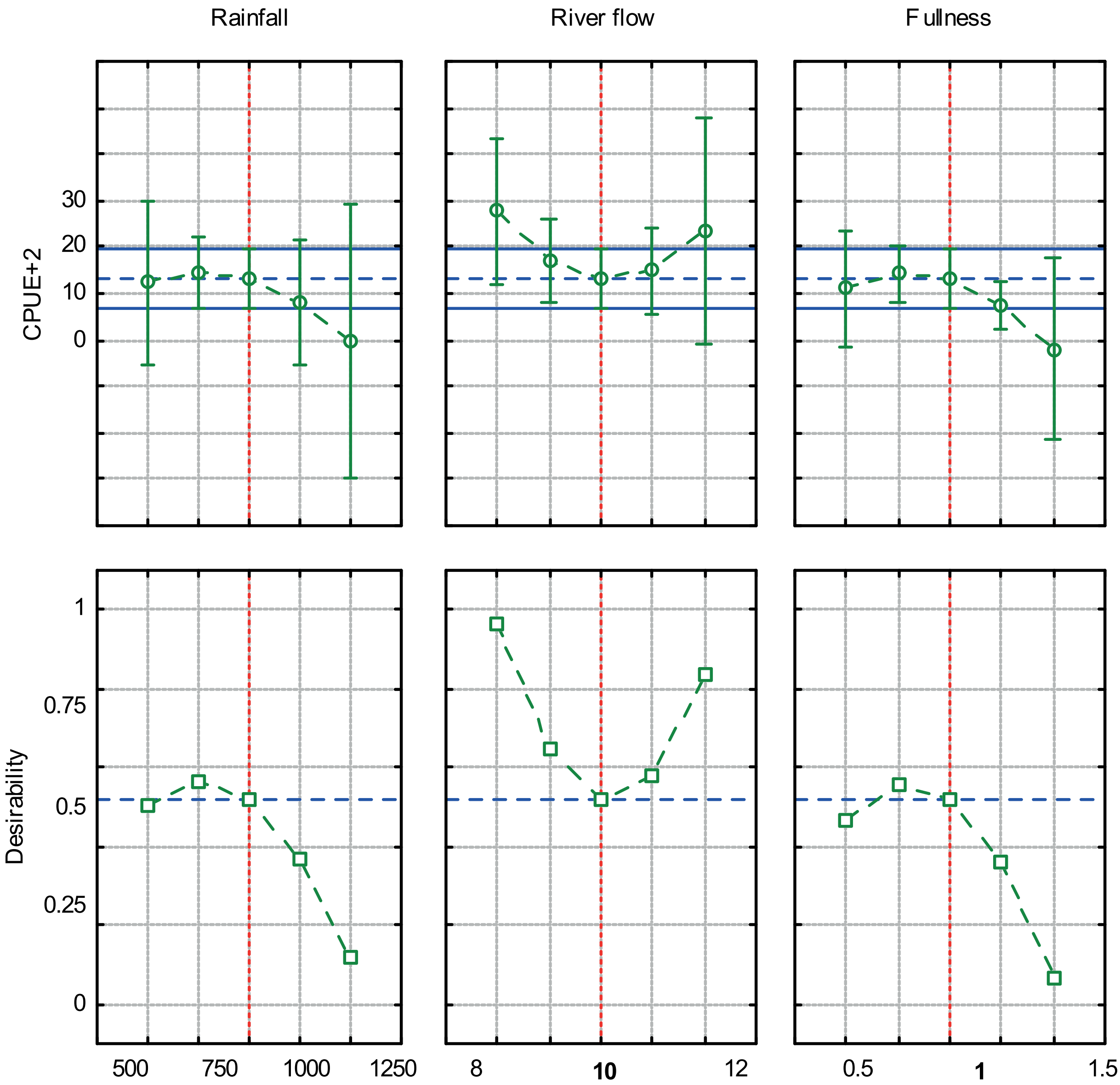


Figure 7. Relationships between CPUE+2 (marron per person per day) and independent variables of annual Collie rainfall ('Rainfall', mm), annual volume of water flowing down the Collie River into Wellington Dam ('River flow', ML) and fullness of Wellington Dam in January ('Fullness', arcsin percentage). Upper figures, modelled effect of each variable on CPUE+2. Red dotted vertical lines, mean of each predictor variable; blue lines, mean (dotted) and 95% confidence limits (solid lines) for CPUE+2; green error bars, 95% prediction limits of the environmental data for CPUE+2. Lower figures, desirability plots of each predictor variable for CPUE+2 while other independent variables are held constant at the levels indicated by the red vertical lines. Higher desirability levels produce higher CPUE+2.

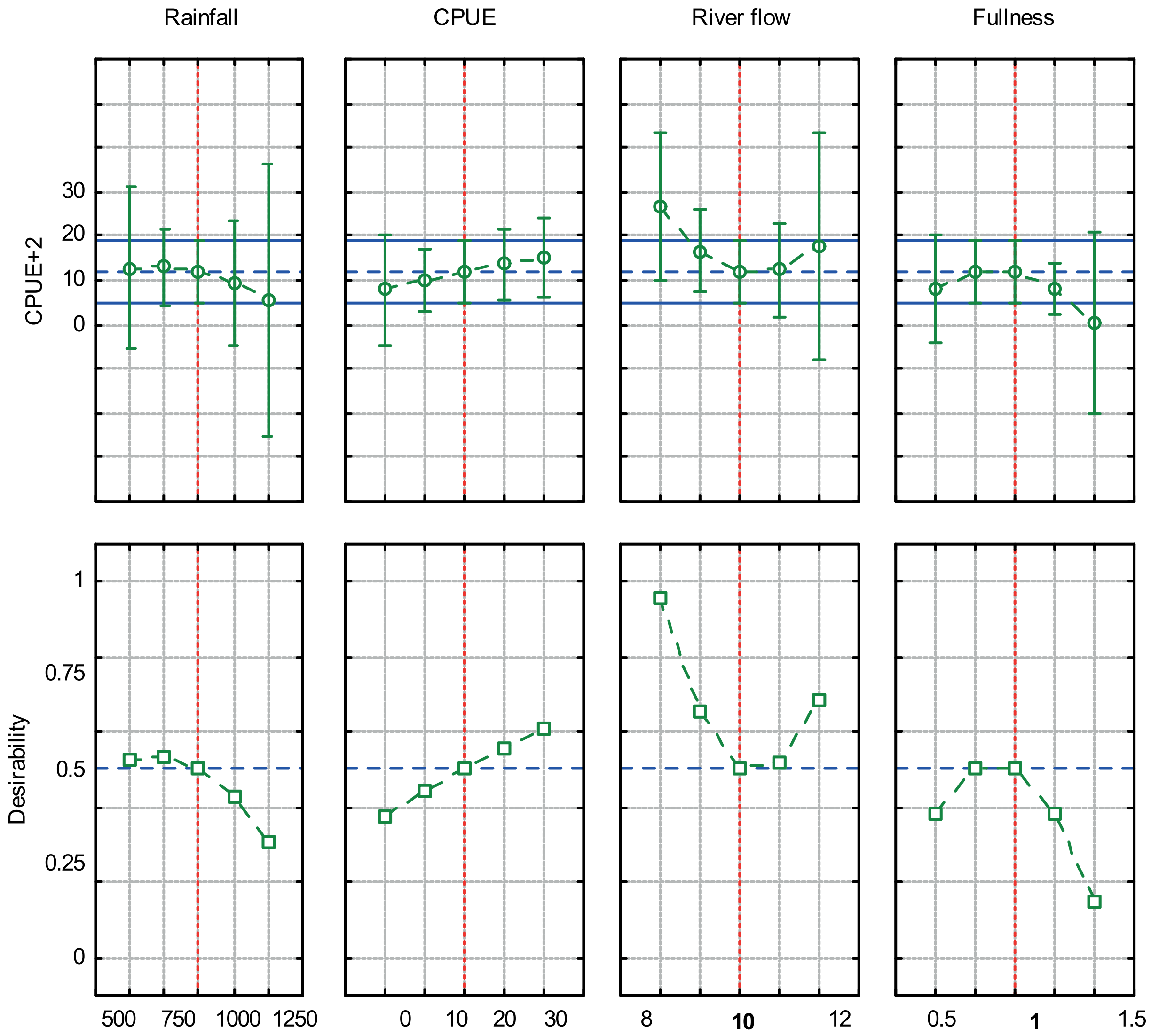


Figure 8. Relationships between CPUE+2 (marron per person per day) and independent variables of annual Collie rainfall (‘Rainfall’, mm), CPUE (previous season, marron per person per day), annual volume of water flowing down the Collie River into Wellington Dam (‘River flow’, ML) and fullness of Wellington Dam in January (‘Fullness’, arcsin percentage). Upper figures, modelled effect of each variable on CPUE+2. Red dotted vertical lines, mean of each predictor variable; blue lines, mean (dotted) and 95% confidence limits (solid lines) for CPUE+2; green error bars, 95% prediction limits of the environmental data for CPUE+2. Lower figures, desirability plots of each predictor variable for CPUE+2 while other independent variables are held constant at the levels indicated by the red vertical lines. Higher desirability levels produce higher CPUE+2.

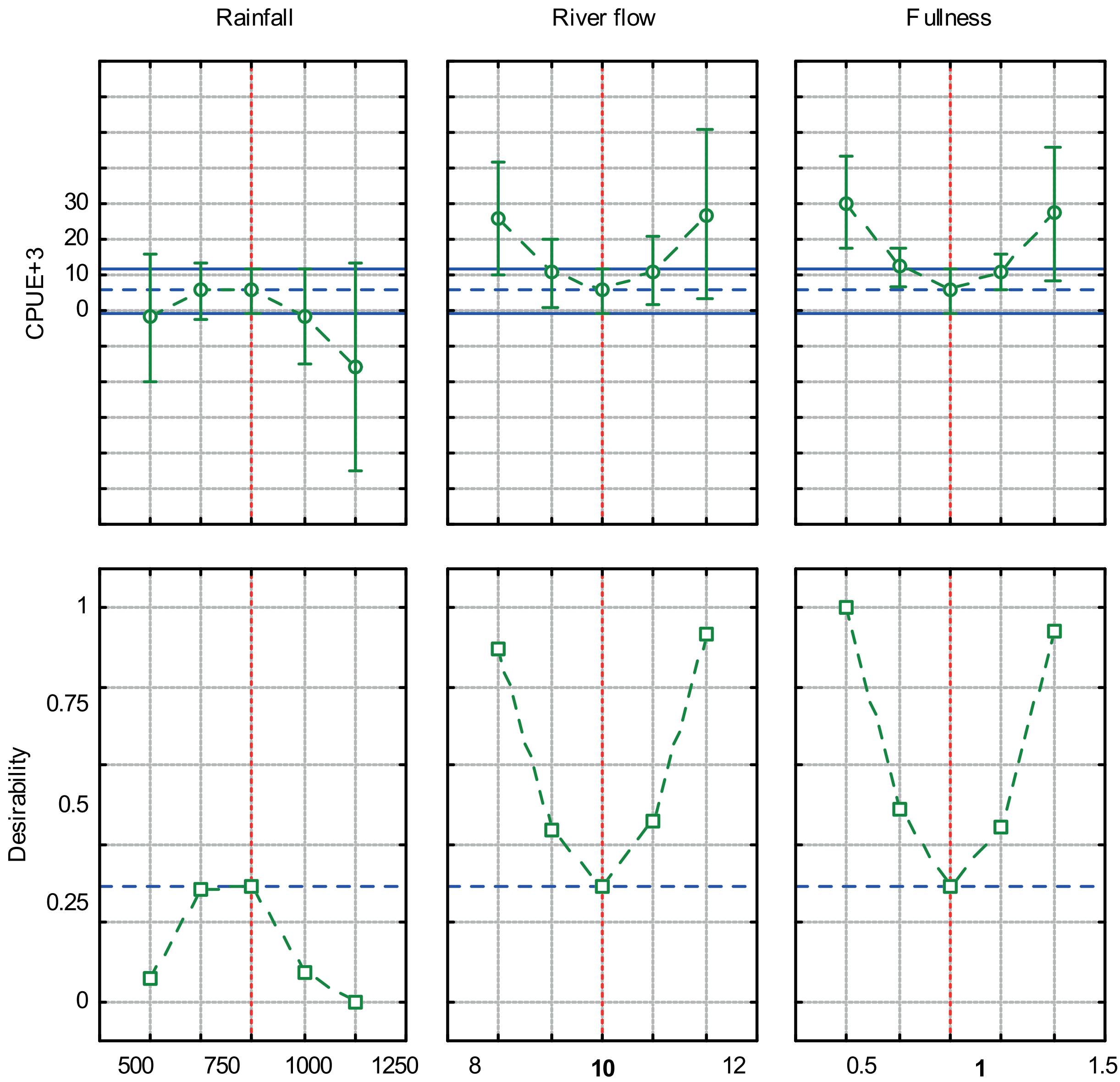


Figure 9. Relationships between CPUE+3 (marron per person per day) and independent variables of annual Collie rainfall ('Rainfall', mm), annual volume of water flowing down the Collie River into Wellington Dam ('River flow', ML) and fullness of Wellington Dam in January ('Fullness', arcsin percentage). Upper figures, modelled effect of each variable on CPUE+3. Red dotted vertical lines, mean of each predictor variable; blue lines, mean (dotted) and 95% confidence limits (solid lines) for CPUE+3; green error bars, 95% prediction limits of the environmental data for CPUE+3. Lower figures, desirability plots of each predictor variable for CPUE+3 while other independent variables are held constant at the levels indicated by the red vertical lines. Higher desirability levels produce higher CPUE+3.

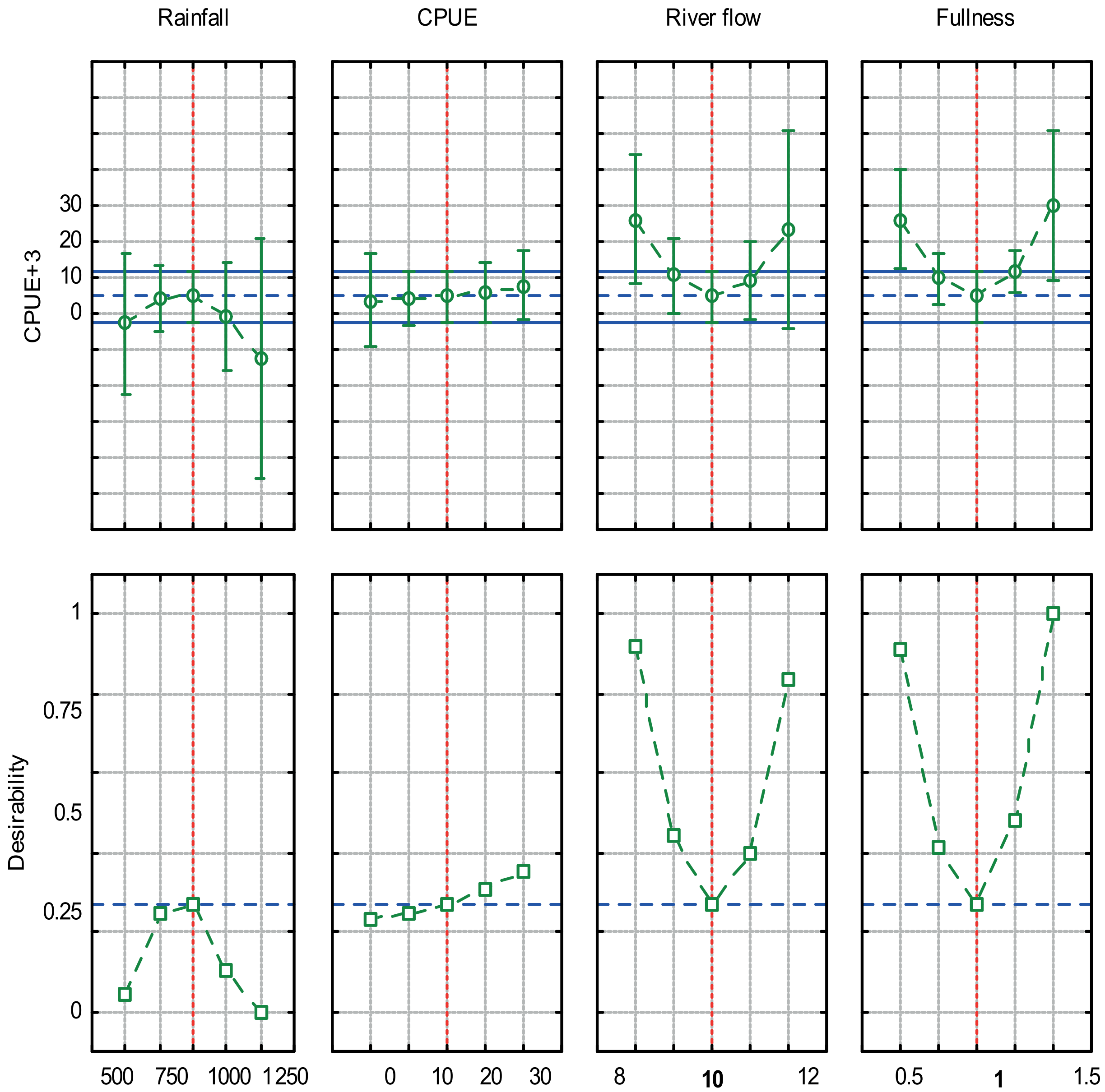


Figure 10. Relationships between CPUE+3 (marron per person per day) and independent variables of annual Collie rainfall (‘Rainfall’, mm), CPUE (marron per person per day), annual volume of water flowing down the Collie River into Wellington Dam (‘River flow’, ML) and fullness of Wellington Dam in January (‘Fullness’, arcsin percentage). Upper figures, modelled effect of each variable on CPUE+3. Red dotted vertical lines, mean of each predictor variable; blue lines, mean (dotted) and 95% confidence limits (solid lines) for CPUE+3; green error bars, 95% prediction limits of the environmental data for CPUE+3. Lower figures, desirability plots of each predictor variable for CPUE+3 while other independent variables are held constant at the levels indicated by the red vertical lines. Higher desirability levels produce higher CPUE+3.

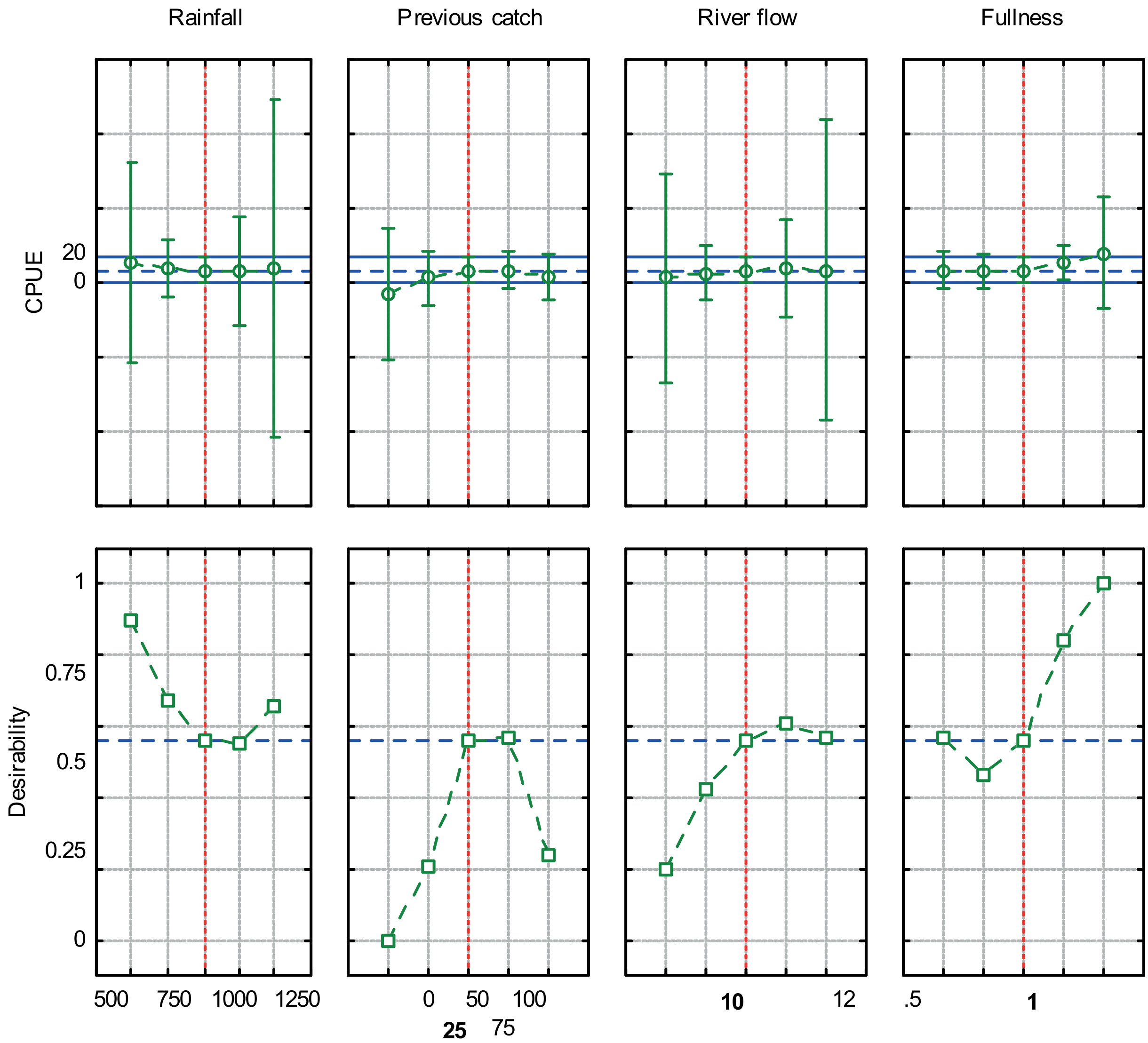


Figure 11. Relationships between CPUE (marron per person per day) and independent variables of annual Collie rainfall ('Rainfall', mm), previous catch (number of marron x 1,000), annual volume of water flowing down the Collie River into Wellington Dam ('River flow', ML) and fullness of Wellington Dam in January ('Fullness', arcsin percentage). Upper figures, modelled effect of each variable on CPUE. Red dotted vertical lines, mean of each predictor variable; blue lines, mean (dotted) and 95% confidence limits (solid lines) for CPUE; green error bars, 95% prediction limits of the environmental data for CPUE. Lower figures, desirability plots of each predictor variable for CPUE while other independent variables are held constant at the levels indicated by the red vertical lines. Higher desirability levels produce higher CPUE.

3.7 Appendices

Appendix 1. *Variables used in the current study. [BoM, Bureau of Meteorology; WC, Water Corporation of Western Australia; DoE, Department of Environment, Western Australia; DoF, Department of Fisheries, Western Australia]*

Variable	Description	Resolution available	How used	Data Manager
Dam fullness	Current volume of dam relative to maximum volume	Weekly	1st December annually	WC
Dam surface area	Current surface area of dam relative to maximum surface area	Weekly	Pre-Recreational Marron Fishery season	WC
Collie rainfall	Rainfall at Collie rain station	Sub-daily	Annual	BoM
Worsley rainfall	Rainfall at Worsley rain station	Sub-daily	Annual	BoM
Harris rainfall	Rainfall at Harris rain station	Sub-daily	Annual	BoM
Valern rainfall	Rainfall at Valern rain station	Sub-daily	Annual	BoM
Mungalup Tower gauge	Collie River gauging station near Mungalup Tower	Weekly	Annual	DoE
James Crossing gauge	Collie River gauging station near James Crossing	Weekly	Annual	DoE
Coolangatta gauge	Collie River gauging station near Coolangatta property	Weekly	Annual	DoE
Collie gauge	Collie River gauging station near Collie Township	Weekly	Annual	DoE
Wellington effort	Total Recreational Marron Fishery effort (days) to Wellington Dam	Recreational Marron Fishery Season	Annual effort (days)	DoF
Wellington Catch-per-unit-effort	CPUE (marron per fisher per day) to Wellington Dam	Recreational Marron Fishery Season	CPUE (marron per fisher per day)	DoF
Berry-up rate	Proportion of berried females compared to total number of females in pre-season survey	Annual estimate	% berry rate	DoF
Pre-season numbers	Number of marron in fisheries independent pre-season surveys	Annual estimate	Total estimate from three passes	DOF

Appendix 2. Summary of normality tests and transformations (as required) on the environmental data set for Wellington Dam Recreational Marron Fishery

Variable	Shapiro-Wilk W	P	Normal ?	Transformation or comment	Post-transformed W (P)
Dam fullness (%)	0.87221	0.03636	N	Arc-sin	0.88186 (0.05058)
Dam surface area (%)	0.87567	0.04091	N	Arc-sin	0.88111 (0.04930)
Collie rain – Annual	0.95521	0.64400	Y	Nil	
Worsley rain – Annual	0.98296	0.98845	Y	Nil	
Valern rain – Annual	0.84131	0.01696	N	Out	
Harris rain – Annual	0.94789	0.52847	Y	Nil	
Mungalup gauge - annual	0.82493	0.01032	N	Ln	0.93409 (0.34788)
James gauge- annual	0.96633	0.82418	Y	Nil	
Coolangatta gauge- annual	0.81750	0.00828	N	Ln	0.93456 (0.35309)
Collie gauge- annual	0.70429	0.00041	N	Ln	0.95206 (0.59313)
Wellington effort	0.87466	0.04881	N	Square root	0.94967 (0.55558)
Recreational Marron Fishery days	0.74939	0.00088	N		
Wellington CPUE	0.95875	0.70244	Y	Nil	
CPUE Lag 1	0.95875	0.70244	Y	Nil	
CPUE Lag 3	0.95875	0.70244	Y	Nil	
% berry-up	0.93852	0.43800	Y	Arc-sin	0.92855 (0.32619)
Pre-season	0.96621	0.84530	Y	Nil	
Pre-season 1 pass	0.92459	0.28911	Y	Nil	

Appendix 3. Summary results of exploratory PCA analyses on Wellington Dam sub-catchment and Recreational Marron Fishery data

Principal Component Axis	1	2	3	4	5
Major variable(s) contributing to the axis	Rainfall and river gauging data	Dam fullness	CPUE	Pre-season abundance	Berry-up rate
Amount of variance in the data explained by the axis	~ 50 %	~ 15 %	~ 12 %	~ 9 %	~ 7%
Cumulative variance	~ 50 %	~ 65 %	~ 77 %	~ 86 %	~ 93 %

Appendix 4. Summaries of the final PCA analysis on Wellington Dam sub-catchment and Recreational Marron Fishery data, 1973–2004

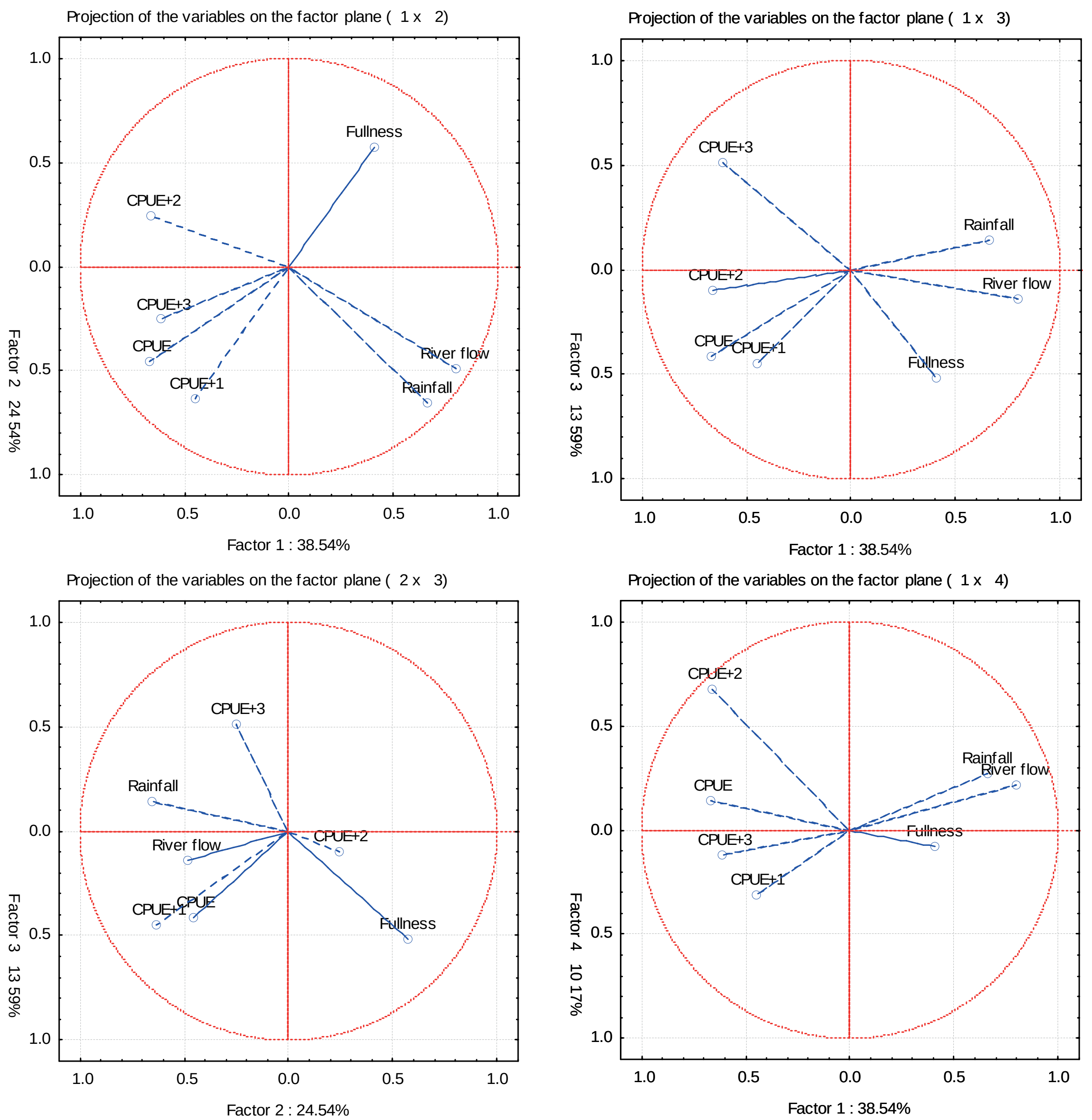
Weightings of each environmental variable on the principal component axes in the PCA analyses on Wellington Dam sub-catchment and Recreational Marron Fishery data, 1973–2004.

Variable	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Factor 7
Rainfall	0.661038	-0.652416	0.138934	0.271712	-0.095631	-0.002999	-0.187342
CPUE	-0.670910	-0.456294	-0.411805	0.138602	-0.167308	0.353234	0.010786
River flow	0.795594	-0.486347	-0.140541	0.218402	-0.138167	-0.079116	0.194156
CPUE+1	-0.449047	-0.632869	-0.449100	-0.312036	0.116092	-0.290575	-0.029399
CPUE+2	-0.659794	0.241578	-0.100898	0.672832	0.021191	-0.207248	-0.005269
CPUE+3	-0.612156	-0.253388	0.510786	-0.122885	-0.523364	-0.102267	0.026214
Fullness	0.407626	0.569554	-0.519763	-0.078000	-0.474394	-0.068473	-0.058935

Summaries of PCA analyses on Wellington Dam sub-catchment and Recreational Marron Fishery data, 1973–2004.

Factor	Eigenvalue	% of total variance	Cumulative eigenvalue	Cumulative % variance
1	2.697928	38.54183	2.697928	38.5418
2	1.717865	24.54092	4.415793	63.0828
3	0.951565	13.59379	5.367358	76.6765
4	0.711991	10.17130	6.079349	86.8478
5	0.569114	8.13019	6.648463	94.9780
6	0.273575	3.90822	6.922038	98.8863
7	0.077962	1.11374	7.000000	100.0000

Appendix 5. Projections of variables used in the PCA displayed on the major axes. Upper left, PCA 1 and PCA 2; Upper right, PCA 1 and 3; Lower left, PCA 2 and 3; Lower right, PCA 1 and 4. Length of blue line indicates the weight (correlation) of each variable. Percentages refer to the percent of variation in dataset accounted for by each axis. Variable labels: River flow, Collie River annual gauge; Rainfall, Collie annual rainfall; Fullness, Wellington Dam fullness in January; CPUE, catch per unit effort of marron; CPUE+1, catch per unit effort of marron lagged by one year; CPUE+2, catch per unit effort of marron lagged by two years: CPUE+3, catch per unit effort of marron lagged by three years



4.0 Identifying and ranking the impacts of sources of mortality of marron in southwestern Australia

Martin de Graaf, Vinh Nguyen and Stephen Beatty

4.1 Introduction

Biodiversity 'hotspots' are areas of concentrations of endemic species undergoing exceptional loss of habitat (Myers et al. 2000). Of the 34 currently recognized biodiversity hotspots in the world only one is situated in Australia; the southwest corner of Western Australia (Conservation International 2007).

Ten species of native freshwater fish occur in southwestern Australia, eight of which are endemic to the region (Morgan et al. 1998; Allen et al. 2002). None of the native fish species are large piscivorous predators; only the freshwater cobbler (*Tandanus bostocki*) attains a maximum size greater than 150 mm total length (TL) (Morgan et al. 1998; Allen et al. 2002).

In Western Australia all freshwater crayfish (six *Cherax* spp. and five *Engaewa* spp.) are entirely endemic (100%) and restricted to the Southwest Coast Drainage Division compared to that of the freshwater fish, 80% of which are endemic (Morgan et al. 1998).

It has been suggested that introduced angling species (rainbow trout, brown trout, Tay et al. 2007) and feral predatory fish (redfin perch, Morgan et al. 2002) may have a negative impact on marron populations by limiting recruitment. These authors found marron to be a significant part of the diet of both rainbow trout and redfin perch, in at least in the largely habitat deficient water supply dams. However aside from these studies (and Molony et al. 2004) these is a general lack of information on the impact of introduced fish on native fauna in Western Australia; despite the ongoing stocking of trout in these rivers. Therefore there is a need for a need for a comprehensive analysis of temporal, spatial and ontogenetic changes in the diets of large (>150mm) introduced and native fish species.

Furthermore, a range of other mortality sources (e.g. turtles, birds, water rats, recreational fishing, loss of habitat) exist that may impact marron populations. The aim of the study is to identify and rank sources of mortality of marron with special emphasis on introduced predatory fish.

4.2 Materials and Methods

Dietary analysis

Potential predators like longneck turtle (*Chelodina oblonga*), water rat (*Hydromys chrysogaster*) and aquatic birds are protected species under state legislation. None of these animals were collected during this study for dietary analysis. Diet information of these species in Western Australia is very limited and the available information on their diet is based on historical data and observations on similar species in the eastern states.

Predatory fish were collected using gillnets, seine nets and hook-and-line from a range of dams and rivers (Fig. 1) in the southwest of Western Australia between February 2000 and June 2007. Stomach (*Perca fluviatilis*, *Oncorhinus mykiss* and *Salmo trutta*) or anterior gut (*Tandanus bostocki*) contents were identified and allocated to one of eight diet categories (FISH = fish, MAC = freshwater crayfish *Cherax* spp, shrimp = freshwater shrimp [Palaemonidae], INS = insect, LAR = insect larvae, ZOO = zooplankton, MOL = mollusc, OTH = other [non-edible items like pieces of wood, rock, cigarette butts, fishing gear etc]). Contents were transferred to a petri-dish and the percentage contributions made by the different dietary categories to the total volume were estimated to the nearest 5%. In addition, individual prey items were identified to species level and measured to the nearest 1 mm T.L. (for fish) or OCL (for freshwater crayfish) when possible. However it is important to note that soft-bodied food items are exceptionally difficult to identify when using the gut-content-analysis method for dietary analysis. Therefore the soft-bodied food items in the gut contents of the fish are likely to have been underestimated in this study.

Recreational marron fishery

Data on estimated total catch, CPUE, size distribution, temporal and spatial variation in effort and licence usage, were obtained through a voluntary logbook program (recorded since 1970) and a centralised phone survey (recorded since 2000). Logbook holders (n=50-100) were asked to complete details of each fishing trip, including location, duration, gear, and number, size and sex of retained marron. The phone survey (n=800 random licensed recreational fishermen) collected information on licence usage, fishing location, gear and CPUE. The annual catch is estimated from the data obtained by the random phone survey.

Research surveys of marron stocks were conducted using drop nets in February and/or March 1970, 1971, 1983, 1988, 1989 and 1990 at the Colonels in the Warren River (fig. 1). In 2006, three sites (Colonels, Bannister Rd Bridge, National Park) were surveyed in the Warren River. In each annual survey, 15 baited drop-nets were set at sunset in an overlapping pattern at a maximum depth of 5 m. The nets were lifted three times at hourly intervals. All marron captured with the 15 drop-nets during one pass were retained (pooled) in the same bin. On completion of nightly sampling, all marron within each pass (15 drop net catches pooled) were measured to the nearest 0.1 mm OCL and sexed. In 2006 data from the three sites were pooled before analysis. CPUE of legal size marron (no. legal size marron/hour/dropnet) and percentage of legal size marron in the total catch were used to monitor changes in average size and relative abundance of marron stocks in the Warren River.

4.3 Results

Dietary analysis

Overall Composition

Size-specific changes in the diet of the four freshwater fish species are presented in Figure 2. The diet of juvenile (<15 cm SL) *Perca fluviatilis* consisted mainly of zooplankton. A shift occurred after 15 cm SL with the contribution of freshwater crayfish and fish in the diet increasing. The diet of individuals larger than 20 cm SL was dominated by freshwater crayfish (>50%). No small (<15 cm SL) *O. mykiss* were collected during this study. The diet of *O. mykiss* smaller than 30 cm SL consisted predominantly of terrestrial and aquatic insects. Freshwater crayfish and fish were only preyed upon by large (>30 cm SL) *O. mykiss*. Unfortunately data on diet composition was only available for large, adult (>30 cm SL) *S. trutta*. Freshwater crayfish and fish formed the major component of the diet of these large individuals. In contrast to the three introduced species, the diet of the native freshwater cobbler consisted mainly of small prey items like insect larvae, insects and zooplankton (Ostracoda). The diet of juveniles (< 15 cm

SL) consisted mainly of zooplankton (Ostracoda) and insect larvae. The diet of *T. bostocki* (> 15 cm SL) was dominated by insect larvae and insects. Freshwater crayfish and fish formed only a minor part of the diet of *T. bostocki* (Fig. 2).

Cherax cainii was the most common freshwater crayfish consumed (~40-90% Fig. 3) by all four large freshwater fish. Only *S. trutta* appeared to prey upon other available native crayfish (~50%) like gilgies (*Cherax. Quinquecarinatus* and *Cherax crassimanus*) and koonacs (*Cherax preissii* and *Cherax glaber*). Both *O. mykiss* and *S. trutta* preyed predominantly on native fish species (galaxids). *S. trutta* also preyed upon *P. fluviatilis* (~17%). *P. fluviatilis* appeared to be highly cannibalistic (Fig. 3).

Temporal variation

Temporal variation in the diet of *P. fluvialtilis* (>20 cm SL) was small, freshwater crayfish and fish dominated throughout the year (Fig. 4). Minor changes occurred during winter and spring when insect larvae formed ~14% of the diet. The diet of *T. bostocki* (>15 cm SL) was also relatively stable throughout the year and was dominated by insect larvae in each season. The diet of small (<30 cm SL) *O. mykiss* was dominated by insects in both Autumn and Spring. Larger *O. mykiss* (>30 cm SL) showed some seasonal variation in dietary composition. In winter and spring, fish and crayfish were the dominant prey items. In summer, insects dominated the diet, while in autumn a large proportion of the *O. mykiss* stomachs contained inedible items like wood, rock and cigarette butts. Few *S. trutta* were available for diet analysis. However, *S. trutta* appeared to prey actively upon fish and crayfish year-round.

Spatial variation

The diet of *P. fluviatilis* was dominated by freshwater crayfish and fish (combined ~80%) in both rivers and dams (Fig. 5). The remainder of the diet consisted of freshwater shrimp in rivers and insect larvae in dams. Small *O. mykiss* (<30 cm SL) fed mainly on insects (>50%) in rivers and dams. Large *O. mykiss* (>30 cm SL) preyed predominately on freshwater crayfish and fish in rivers, and freshwater crayfish and insects in dams. While among small *O. mykiss* a considerable amount of inedible food items were observed among fish collected in the rivers, the opposite was true for the larger individuals where only 40% of the stomach contents of fish obtained from dams contained inedible items. In *S. trutta* freshwater crayfish and fish contributed equally to the diet in both river and dams. The remaining 30% of the diet consisted of insects in rivers and insect larvae in dams.

Prey size

The absolute (mm OCL or mm TL) and relative (Total length prey [mm]/ Total length predator [mm] * 100%) size distributions of whole *C. cainii* and finfish ingested by *P. fluviatilis, O. mykiss* and *S. trutta* are shown in Table 1 and Figure 6. The vast majority of *C. cainii* consumed by the three introduced predaceous fish were juveniles (< 30mm OCL). The three piscivorous introduced species consumed only juvenile *P. fluviatilis* but both juvenile and adult native fish. Average relative prey length of the heavily armoured *C. cainii* was smaller than the average relative prey length of the soft-bodied finfish consumed by each of three predaceous species.

Recreational marron fishery

Figure 7 shows the annual variation in the estimated total catch and CPUE of the Recreational Marron Fishery and major changes to the management (gear, size, effort restrictions) of the fishery since 1971. Annual landings have declined from ~500,000 to 60,000 marron in line with the reduction of the season length from 135 (1971-1972) to 16 days (2003-2006) (i.e. ~88% reduction in both). Average daily landings have been fluctuating around the overall long-term average of 4,100 marron per day (Fig. 8). CPUE has decreased significantly since the 1970s from ~15 to ~5 marron per fishermen, per day (Fig. 7). However, the average weight of retained marron has remained stable at around 230 g since the early 1970s (Fig. 9). In 2007, after a 4 mm increase in minimum legal size, average weight of retained marron increased to almost 300 g.

The Recreational Marron Fishery is mainly a river fishery. Dams have received just ~25% of all the effort since 2000 (Fig. 10). Almost 80% of total dam effort is divided over just three dams, Wellington (~40%), Harvey (~30%) and Waroona Dam (~10%) (Fig. 10). River effort is more evenly distributed among a wider range of rivers (Fig. 10), with the Blackwood, Warren, Collie, Murray and Preston Rivers being the most consistently fished rivers.

The quality of the marron fishery has been declining since the 1970s as illustrated by decreasing total catches and CPUE (Fig. 7, chapter 2). In contrast to this trend, marron stock indices showed that average size and relative abundance of marron, at least in the lower reaches of the Warren River, have remained stable and even improved slightly since the 1970s (Fig. 11).

4.4 Discussion

Relative impacts of the sources of marron mortality

Long neck turtle (*Chelodina oblonga*)

Long neck turtles can be found in most rivers and dams in the southwest of WA. Based on the literature, it is predominantly an opportunistic carnivore/scavenger feeding on carrion, insects and fish (Burbidge 1967; Cann 1978). Although some predation would occur, *C. oblonga* probably does not account for a significant amount of natural mortality in most marron populations.

Water rat (*Hydromys chrysogaster*)

The water rat is an opportunistic omnivore feeding on a wide variety of food items including fish, mussels, freshwater crayfish, young aquatic birds and their eggs, small amounts of grass and rushes, small mice, turtles, frogs, bats and lizards, (McNally 1960; Barrow 1964; Woollard et al. 1978; Fleay 1990). Woollard (1978) found that crustaceans were eaten by 6-9% of the water rats analysed (N=747), contributing to less than 5% of the diet. However, Woollard (1978) likely underestimated the contribution of crustaceans, as soft, fleshy prey items consumed by water rats were difficult to pick up in the analyses (i.e. possibly because water rats peel their prey).

The water rat is known to have the potential to severely impact on marron aquaculture production. Therefore, the species potentially contributes to natural mortality of some marron populations at least on a localised scale where habitat characteristics of the riparian zone allow its inhabitation (mostly in rivers rather than the highly altered dam environment). However, in terms of the overall sources of mortality, this would likely be insignificant.

Aquatic birds

Marron inhabit lakes, dams and permanent, deep pools in rivers throughout the southwest of Western Australia and usually do not occur in shallow, temporary water bodies like, swamps, seasonal rivers or floodplains. The impact on marron stocks of wading birds like egrets, herons and grebes and shallow diving birds like ducks, which are common in swamps and floodplains, is therefore negligible.

Diving birds like cormorants (*Phalacrocorax* spp) and darters (*Anhinga* sp), which are able to forage underwater for 30-45 s and reach depths of ~10 m (Hustler 1992), are, potentially much more likely to impact freshwater crayfish populations. Darters, however, are strictly piscivorous as was shown from stomach content analysis by Vestjens (1975) in New South Wales, by McNally (1957) in Victoria and by Dostine and Morton (1988) in Northern Territory. Pied cormorant (*Phalacrocorax varius*) and Great cormorant (*Phalacrocorax carbo*) are more abundant in estuaries and coastal areas than freshwater lakes, rivers or floodplains and feed mainly on fish (70-100%) (Serventy 1938; McNally 1957; Morton et al. 1993). Little Black cormorant (*Phalacrocorax sulcirostrus*) and especially the Little Pied cormorant (*Phalacrocorax melanoleucos*) are most frequently encountered in freshwater systems. Little Black cormorant hunt socially for small fish (55% McNally 1957; 74% Miller 1979) and, to a lesser extent, freshwater crayfish (10% McNally 1957; 21% Miller 1979). The most common predator of freshwater crayfish is the Little Pied Cormorant. This species tends to hunt alone rather than in groups, feeding on freshwater crayfish (53% McNally 1957; 43% Miller 1979) and small fish (14% McNally 1957; 24% Miller 1979). Serventy (1938) analysed the stomach contents of 15 Little Pied Cormorant collected from freshwater systems in the southwest of WA and found that freshwater crayfish (*C. cainii* and *C. quinquecarinatus*) formed 80% of the identified food items.

It widely assumed, that the impact of birds on fish populations in aquatic food webs is often underestimated (Steinmetz et al. 2003), however Engström (2001) demonstrated that high densities of cormorants had no effect on fish numbers or biomass in a Swedish lake. No such data exist for freshwater crayfish. However, as with the water rat, they are thought to consume large volumes of marron in aquaculture facilities. Therefore they may contribute to at least some seasonal natural mortality of marron populations; particularly in the shelter habitat deficient water supply dams in the region.

Freshwater Cobbler (*Tandanus bostocki*)

The freshwater cobbler (*T. bostocki*) is endemic to the southwest of Australia and is found in most waterways (Coy 1979; Allen 1982). It is most active at night when foraging for food (Morrison, 1988). Fish form only a minor dietary component for *T. bostocki* of any size (Fig. 2 and Hewitt 1992). Like most other catfish species (Allen et al. 2003) the diet of *T. bostocki* consists predominantly of benthic invertebrates.

The diet of small (<25 cm SL) juvenile *T. bostocki* (Fig. 2) collected from Wellington Dam and Harvey Dam consisted mainly of insect larvae, insects and Ostracoda. These results are similar to the diet composition of small individuals in Wungong Dam (Hewitt 1992). In contrast to Hewitt (1992), marron only formed a moderate component (~15%) of the diet of larger cobbler (>20 cm SL). Furthermore, no whole marron where observed in the anterior dietary tract of *T. bostocki*, only appendages (claws and legs). According to Hewitt (1992) marron formed the main (>90%) dietary component in large cobbler collected in Wungong Dam, although sample size of large cobbler used for dietary analysis and whether or not whole marron or predominantly appendages were ingested, is unclear.

For *Tandanus tandanus,* large crustaceans (freshwater prawn *Macrobranchium australiense* and freshwater crayfish *Cherax neopunctatus*) formed the main component of the diet of large individuals. However, the contribution of freshwater crayfish in the diet only increased in individuals larger than 35 cm (Davis 1977). *Tandanus tandanus* (commonly 45 cm, maximum 90 cm) is significantly larger than *T. bostocki* (commonly 25 cm, maximum 52 cm) (Allen et al. 2002; Beatty personal communication). *Tandanus bostocki* undoubtedly contributes to a degree, to the natural mortality of some marron populations at least a localised scale when relatively high densities of this species exist. However, as with the cormorants and the water rat, overall, this contribution may be relatively minor.

Rainbow Trout *(Oncorhynchus mykiss)*

The results of this (Fig. 2) and other studies (Table 2) revealed a consistent general pattern in ontogenetic diet shifts in *O. mykiss*. Small individuals (<200 mm) feed predominantly on (terrestrial) insect and insect larvae. Between 200-300mm their diet shifts towards larger prey items like native fish and especially crayfish. Large (>300 mm) *O. mykiss* feed mostly on freshwater crayfish.

The diet of small (<300 mm SL) *O. mykiss* showed little spatial and temporal variation (Figs. 4,5). Among large (>300 mm SL) *O. mykiss* crayfish and native fish form significant components of their diet in rivers. While in dams large individuals fed mainly on marron and insects, their stomach also contained a large percentage of inedible food items like cigarette butts and woody debris (40%).

Oncorhinus mykiss consumed both juvenile and adult native fish. However, when feeding on marron, only whole juveniles are preyed upon as shown by the small size of ingested marron (Table 1). Tay et al. (2007) recorded similar small prey sizes (7-23 mm OCL, n=9) for *O. mykiss* feeding on marron in Churchman Brook Reservoir, WA. In Lake Eucumbene (NSW) *O. mykiss* also preyed strictly on juvenile yabby (*Cherax destructor*) (mean 9.3 mm OCL, range 4-32 mm, n=57: Faragher 1983).

Brown Trout (*Salmo trutta*)

Unfortunately only 16 large (>300 mm SL) *S. trutta* were obtained for diet analysis. However, *Salmo trutta* in Western Australia is expected to follow similar ontogenetic changes in diet (Table 2) as demonstrated by Faragher (1983). The diet of large (>300 mm SL) *S. trutta* consisted roughly of one-third native fish (galaxids), one-third crayfish and one-third insect/insect larvae, with little spatial and temporal variation.

Salmo trutta is the only species that appeared to feed on all native *Cherax* species and not just marron. This probably reflects differences in habitat use and spatial segregation in rivers. *Salmo trutta* is more common in the shallow seasonal sections of rivers where gilgies and koonacs are more abundant.

Like *O. mykiss, S. trutta* preyed on juvenile and adult native fish but only on small juvenile marron (Table 1, Fig. 6). Juvenile crayfish predation was also demonstrated for *S. trutta* ingesting small *C. destructor* in Lake Eucumbene (mean 16.6 mm OCL, 5-48 mm, n=266, Faragher 1983).

Redfin Perch (*Perca fluviatilis*)

Redfin perch followed ontogenetic trajectories feeding on progressively larger prey, shifting from zooplankton (<150mm SL) to insect larvae and freshwater shrimp (150-200 mm SL) to marron and fish (>200mm SL) (Fig. 2). In WA similar shifts from planktonic crustaceans to benthic decapods and fish have been recorded for *P. fluviatilis* in the Collie River (Pen and Potter 1992) and Big Brook Dam/Lefroy Brook (Morgan et al. 2002). In both riverine and lacustrine environments the diet of large (>200 mm SL) *P. fluviatilis* consisted of crayfish (~55%) and fish (~25%). Morgan et al (2002) also found no difference in diet composition of large (>200 mm TL) *P. fluviatilis* in Big Brook Dam and immediately below the dam in Lefroy Brook. Of note, is the apparent lack of temporal variation in the diet. Marron is not only an important food source during the summer (Morgan et al. 2002) but also throughout the rest of the year (40-60%). Fish (15-40%) is the other main component of the diet of *P. fluviatilis*. However, unlike both trout species, *P. fluviatilis* is mainly cannibalistic, feeding on small juvenile *P. fluviatilis*. Cannibalism is not uncommon in *P. fluviatilis* (see Morgan et al. 2002 and references therein) but in the Collie River *P. fluviatilis* preyed upon native fish (Pen and Potter 1992). Similar to both trout species, only juvenile marron (<30mm OCL) were susceptible to predation by *P. fluviatilis*.

Recreational marron fishery

The impact of the recreational fishery on marron stocks has steadily declined since the 1970s. During this period legal fishing mortality has decreased from an estimated ~ 500,000 in the 1970s to ~50,000 marron per year since 2003. The Recreational Marron Fishery has been heavily managed since the 1950s (Table 3). A wide range of management methods including minimum legal size, increased gear restrictions, decreased bag limits and especially decreased season length, have greatly reduced total annual catch and CPUE.

Since the 1970s the average daily landings of the Recreational Marron Fishery have fluctuated around ~4000 marron (Fig. 8). This apparent straightforward correlation between season length and total catch (i.e. 88% reduction in both) makes adjustments in season length one of the most powerful and simple tools for management to control the annual catch.

CPUE has decreased from ~15 marron per trip in the 1970s to ~5 marron per trip in the 2000s. Over the last 50+ years numerous management initiatives have been introduced (e.g. gear changes Chapter 2) making it progressively more difficult to catch marron. Therefore, an increase in fisheries regulations and not a decline in marron stocks might explain the observed gradual reduction in CPUE. This is corroborated by the few fishery-independent data that exist (Warren River, Fig. 11), showing not a decline but even a slight increase in legal size marron in a highly fished river (Fig. 10).

Relative abundance indices based on fishery-dependent catch per unit effort data are notoriously problematic and at best poor indicators of true stock abundance (Maunder et al. 2006). This stresses the need for an expanded robust, solid fishery-independent monitoring program (see Chapter 7), in addition to the existing long-term and well-designed fishery-dependent log book and phone surveys, to determine true marron stock abundance and evaluate the performance of changes in management strategies.

The present level of exploitation appears to pose little threat to the sustainability of marron populations and overfishing (growth or recruitment) appears not to be a significant issue. Growth overfishing might occur when population mean size is reduced over successive fishing seasons. Fishery dependent data (Fig. 9) illustrated that the mean size (weight) at harvest has been stable at around 230 g since the early 1970s. Furthermore, fishery-independent research surveys in the Warren River, one of the most popular marroning rivers, also demonstrated little change in the average size of marron since the 1970s. Indicators of recruitment overfishing include, a greatly reduced spawning stock, low recruitment in successive years and/or the mean age/size at harvest falling below the mean age/size at maturity. In 1952 minimum legal size was set at 76mm CL (Table 3). Mean size at harvest has been significantly larger than mean size at maturity for almost all river and dam populations since 1952 (see Chapter 6 for exceptions). Therefore, these appear adequate to prevent recruitment overfishing.

4.5 Ranking mortality, interspecific predation and marron population bottlenecks

A schematic overview of the impact of different sources of mortality on *C. cainii* is shown in Figure 12. The impact of natural predation by native birds, water rats and turtles is expected to be limited. Even if these species had a significant impact on marron stocks, management options to reduce predation by these species would be limited due to the vulnerable and protected status of water rats, aquatic birds and longneck turtles.

Unlike the other sources of mortality, the Recreational Marron Fishery specifically targets large mature individuals. Although harvesting smaller, juvenile crayfish is expected to have less impact on freshwater crayfish populations than large reproductive individuals (Momot et al. 1978), the relative small number, especially compared to the 1970s, of adult marron landed annually by the Recreational Marron Fishery most likely has little effect on overall abundance.

A common source of natural mortality throughout every life-stage is cannibalism. Crayfish are susceptible to cannibalism during moulting or due to direct predation by larger individuals. Cannibalism is accepted to frequently occur in natural freshwater crayfish populations (Holdich, 2002 and references therein). High mortalities due to cannibalism are common when crayfish are held at high densities (80% Chapter 9; 60-93% Jones 1981; 75-91% Isely and Eversole 1998). In freshwater crayfish aquaculture it is common procedure to separate the juveniles from the females after release to avoid significant losses of juveniles due to predation by the adult female crayfish. The risk of cannibalism can be reduced by the availability of adequate heterogeneous habitat and the presence of high quality food (Holdich, 2002 and references therein).

Despite the fact that a wide range of predators (invertebrates, fish, amphibians, reptiles, birds and mammals) may feed on freshwater crayfish, few have been shown to significantly effect crayfish abundance (Hogger 1988; Foster and Slater 1995). Predatory fish are the most important predators of freshwater crayfish (Nyström 2002). However their overall impact on population sustainabitlity is questionable. Freshwater crayfish and especially the large, long-lived marron, are only susceptible to predation by fish during the short juvenile life-stage as clearly demonstrated in Figure 6. Due to a rigid exoskeleton marron quickly outgrow the gape-limited predators like trout and redfin perch. Only large adult predatory fish feed on juvenile marron (Fig. 2). Furthermore, predation of small, juveniles has less impact on crayfish populations than large, mature crayfish (Momot 1978). Not all studies have reported a negative relationship between the abundance of predatory fish and the abundance of crayfish (Nyström 2002; and references therein). Collins et al. (1983) showed that high predatory fish densities did not necessarily reduce crayfish abundance, but merely affected their behaviour. Crayfish from lakes with high predator densities were more nocturnal, more shelter-bound and less active than those from a lake without predators.

Tay et al. (2007) stated that in habitat limited water bodies "*O. mykiss* is likely to have a considerable impact on marron populations and may compromise some elements of this iconic fishery." Like-wise Morgan et al. (2002) suggested "*P. fluviatilis* may be severely inhibiting marron recruitment and inflicting far greater damage on the marron resource than recreational fishing." Both studies, like the present one, prove that marron forms an important part of the diet of these predatory fish during certain stages of their life. However, no evidence is provided that this predation has any actual impact on marron density and population structure. To quantify the impact of predatory fish requires further, more controlled experiments.

Marron and introduced predatory fish have coexisted in rivers and dams for over one hundred years without any sign of displacement, unlike for example the exclusion of native crayfish by the introduced brown trout in some habitats in New Zealand (Shave et al. 1994). More importantly the highest marron densities (Chapter 7) in 2006 were recorded in the Warren River (20.3 ± 3.3 CI marron per trap) and Wellington Dam (27.8 ± 4.7 CI marron per trap). Wellington Dam supports a redfin perch and small brown trout population while the Warren River is by far the most productive river for redfin perch, rainbow trout and brown trout. On the other hand the upper reaches of the Margaret River have no introduced predatory fish but had significantly lower densities of marron (4.7 ± 0.8 CI marron per trap; de Graaf unpublished results).

Nonetheless it appears that despite the large number of juvenile marron eaten by predatory fish, this predation does not appear to affect the sustainability of marron populations. This suggests that predation of *C. cainii* by predatory fish may subsequently reduce the intra-specific competition between juveniles for habitat and resources, in turn reducing the natural level of cannibalism.

In contrast to freshwater crayfish, native freshwater fish are more susceptible to predation by the *P. fluviatilis*, *O. mykiss* and *S. trutta*. The soft-bodied, native fish of the southwest have no natural fish predators. Unlike marron, the small sized native fish are susceptible to predation throughout their whole life. Numerous studies have proven that the introduction of trout in (Australian) rivers and dams is the cause for the elimination or strong decline of native fish, especially Galaxiidae (Frankenberg 1966; Cadwallader 1975; Tilzey 1976; Jackson and Williams 1980; Morgan et al. 2002). The introduction of these species has undoubtedly contributed to the decline or loss of some populations of native fishes in certain aquatic systems in the southwest of Western Australia (e.g. Morgan and Beatty 2003).

Redfin perch are a shoaling species preferring deep, slow-flowing water with abundance of vegetation and snags (Allen et al. 2002). In the Collie River, *P. fluviatilis* was only found in the permanent main channel and not in seasonal tributary creeks or flood waters (Pen and Potter 1992). In contrast to *P. fluviatilis* the habitat requirements of the rheophilous trout species are markedly different. Trout commonly occur in cool, well-oxygenated waters, usually in streams with moderate to swift flow and migrate frequently upstream into small seasonal tributaries or feeder streams with gravel beds. The differentiation in habitat is, for example, illustrated by the common occurrence of gilgies and koonacs, freshwater crayfish species in the diet of both trout species. Unlike *C. cainii*, marron, gilgies and koonacs inhabit shallow seasonal streams.

Substrate (i.e. benthic habitat type) is known to structure freshwater crayfish populations and affect density, growth rates, length-frequency distributions, predation and recruitment success (France et al. 1991 and references therein). The availability of structural shelters, such as crevices in rocks, is the critical resource bottleneck (Hobbs 1991). Shelter provides protection against predation, including cannibalism, during vulnerable phases of crayfish life history (i.e. reproduction and moulting). The density of marron populations in the lower sections of rivers and especially in dams, are more likely to be habitat limited (Chapters 7 and 8: Molony and Bird 2005) rather than being overfished or limited by predators. That is, the degree of complex hide habitat influences recruitment rates and increases densities by reducing inter and intra-specific predation. Between 2007 and 2012 a large-scale artificial reef project in Drakesbrook Dam should provide further insight into the role of predatory fish and habitat availability on marron population dynamics. The range of marron within southwest rivers is primarily determined by environmental variables (Chapter 1). Over the last few decades, environmental degradation (e.g. low rainfall, salinity) in the upper reaches of many rivers (Mayer et al 2005) appeared to have restricted marron populations to the lower coastal reaches of different river systems (Chapter 1). Although overall the range of marron in rivers may have declined (Chapter 1), since the 1970s population abundance within these reduced ranges appeared to have been stable and even increased slightly. Within these reduced ranges the critical resources bottleneck is most likely the availability of suitable habitat and not predation by native or introduced predators or the heavily regulated Recreational Marron Fishery.

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4.7 Tables

Table 1. Overview of the absolute and relative length of *C. cainii* and fish species, ingested by *P. fluviatilis*, *O. mykiss* and *S. trutta*.

a) *C. cainii* prey

	Absolute length (mm OCL)			Relative length (TL /TL)			n
	avg	95%CI	range	avg	95%CI	range	
P. fluviatilis	17.1	1.4	5-40	18.3	1.4	5.4-40.1	112
O. mykiss	15.1	2.5	9-25	12.4	1.6	7.9-18.8	13
S. trutta	24.3	11.3	14-34	16.1	7.3	8.7-20.5	3

b) Fish species prey

	Absolute length (mm TL)			Relative length (TL /TL)			n
	avg	95%CI	range	avg	95%CI	range	
P. fluviatilis	76.6	9.4	10-138	29.6	3.8	4-61	52
O. mykiss	67.9	22.4	29-117	17.5	4	9-24	7
S. trutta	88	10.7	67-106	24.7	2.9	19-30	7

Table 2. Overview of the contribution of freshwater crayfish to the diet of *O. mykiss* and *S. trutta* in river and dams in Western Australia, Victoria and New South Wales. References: a = Jenkins 1952, b =Pusey and Morrison 1989, c = Tay et al. 2007, d= Pidgeon 1981, e = Faragher 1983, f = Tilzey 1976, g = Jackson 1978.

Size	n	Crayfish		Insect		Native fish		Ref	Location
		Vol (%)	Occ (%)	Vol (%)	Occ (%)	Vol (%)	Occ (%)		
O. mykiss									
>300mm	9		66		78		-	a	WA: Several rivers
>300mm	35	80		9		3		b	WA: Wungong Dam
23-392mm TL	105	61		35		0*		c	WA: Churchman Brook Reservoir
<200m TL		6		-		-			
200-300mm TL		60		-		-			
>300mm TL		84		-		-			
160-350 mm FL	59	39		52		7		d	NSW: Wollomombi, Guy Fawkes Rivers
240-269		8		-		-			
270-299		14		-		-			
300-329		23		-		-			
330-359		56		-		-			
>359		69		-		-			
<200 mm FL	5	4		-		-		e	NSW: Lake Eucumbene
201-300	37	7		-		-			
301-400	274	6		-		-			
401-500	223	8		-		-			
51-84 mm FL	24	0		100		0		f	NSW: Four Mile Creek
133-455 mm FL	32	0		100		0			
Salmo trutta									
>300mm	1		100		100			a	WA: Big Brook Dam
<300 mm FL	178	0		100		0		g	VIC: Aberfeldy River
<200 mm FL	3	0		-		-		e	NSW: Lake Eucumbene
201-300	26	2		-		-			
301-400	466	23		-		-			
401-500	804	46		-		-			
501-600	102	84		-		-			
>600	6	92		-		-			

Table 3. A brief history of the evolution of regulations regarding recreational marron fishing in Western Australia (adjusted from Molony et al. 2002).

Year	Change in Marron Regulations	Management result
1952	First closed season between September and October annually in scheduled waters (streams of the southwest, not in dams).	Limit of total catch Protection of reproductive animals
	Minimum legal size set at 3 inches (76 mm) RCL.	Protection against recruitment overfishing.
1953	Closed season extended to between September and November in scheduled waters except for the use of snares.	Reduction in effort
	Unattended marron traps now illegal.	Reduction in gear efficiency
1954	Closed season proclaimed between 1 May and 30 November. Some dams now included in scheduled waters.	Limit total catch
1955	Marron prohibited for commercial sale.	Totally recreational fishery
	First ever totally closed season (1 May – 30 November) in scheduled waters (no gear of any type allowed in any scheduled waters during the closed period).	Reduction in effort
1957	Drakesbrook Dam closed for two years.	Moratorium on a single stock
1959	North Dandalup River closed for two years.	Moratorium on a single stock
	Closed season extended from 1 May to 31 December in scheduled waters.	Reduction in effort
1963	Introduction of the Amateur Fisherman's Licence.	Licensing of recreational fishers
	Further gear limitations – maximum of 6 drop nets or traps.	Reduction in effort/CPUE
1969	Closed season between 1 May and 15 December in all scheduled waters.	Changes in effort to reflect fisher behaviour (Christmas holiday period).
	Introduction of the Inland Fisherman's Licence.	Licensing of recreational fishers
	Gear and effort restrictions – 6 drop nets OR 1 snare pole OR 1 scoop net.	Reduction in effort, efficiency and CPUE
	Bag limit of 30 marron per day.	Reduction in catch/CPUE
	Illegal to sell wild captured marron.	Protection of recreational fishery
1970	All waters of the southwest now scheduled. Therefore a totally closed, "Closed" season (1 May and 15 December).	Limit of total catch
1971	All persons > 13 years old require a licence (excluding some pensioners and secondary school students).	Licensing of recreational fishers
1974	Scoop nets, traps, snares and drop nets are the only legal gears. Nets and other techniques illegal.	Reduction in gear efficiency/CPUE
	No diving or snorkelling allowed for marron collection.	Reduction in gear efficiency/CPUE
	Illegal to use any gear in conjunction with a boat.	Reduction in gear efficiency/CPUE
	(First amendment to the fishery act to permit the aquaculture of marron).	Aquaculture
	Mutilation of catch illegal (marron must be whole).	Increase in compliance

1975	Illegal to possess female marron carrying eggs, spawn or larvae.	Protection against reproductive overfishing.
1980	Bag limit reduced to 20 per day.	Reduction in catch/CPUE
	Traps made illegal. Only scoop nets, drop nets and snares are legal.	Reduction in gear efficiency/CPUE
1987	Two year closure due to 5 years of well below-average rainfall.	Moratorium on total fishery.
1988	Formal and public review of all regulations.	Public ownership of fishery
1990	Marron season re-opened with new regulations.	Fishery re-opened
	Bag limit reduced to 10 marron per day.	Reduction in catch/CPUE
	Season reduced to between second Saturday in January to the end of February. Closed season between 1 March and second Friday in January.	Limit of total catch
	Shannon River and Warren River National Park declared “Snare-Only”	Reduction in gear efficiency/CPUE
1993	Margaret River declared ‘snare-only’	Reduction in gear efficiency/CPUE
1994	Harvey Dam declared ‘snare-only’	Reduction in gear efficiency/CPUE
1996	Wellington Dam and Samson Dam declared ‘snare-only’	Reduction in gear efficiency/CPUE
2001	Stirling Dam and Samson dam closed to marron fishing	Access closed by Water Corporation
	Logue Brook Dam declared ‘snare-only’	Reduction in gear efficiency/CPUE
2002	Margaret River above Ten Mile Brook junction closed for marron fishing	Ensure protection of the critically endangered Margaret River or ‘hairy’ marron
	Waroona Dam closed to marron fishing.	Enhance rebuilding marron population after drainage of Waroona Dam
2003	Season reduced to 16 days	Limit on total catch
	Harvey Dam declared ‘trophy water’ (90 mm RCL, bag limit 5)	Reduction in catch/CPUE
	Big Brook Dam, Drakes Brook Dam and Glen Mervey Dam declared ‘snare-only’	Reduction in gear efficiency/CPUE
2006	Waroona Dam reopened and declared ‘snare-only’ and ‘trophy water’ (90 mm RCL, bag limit 5)	Reduction in catch/CPUE and gear efficiency
2007	Minimum legal size increased to 80 mm RCL	Reduction in catch/CPUE
	Season increased to 23 days	Increase of total catch
	Possession limit of 20 marron introduced	Reduction in catch
	Shannon River closed to marron fishing	Biodiversity Conservation only remaining pristine river
	‘Snare-only’ requirement lifted for Warren River National Park	Increase in gear efficiency
	Hutt River declared ‘trophy water’ (90 mm RCL, bag limit 5)	Reduction in catch/CPUE

4.8 Figures

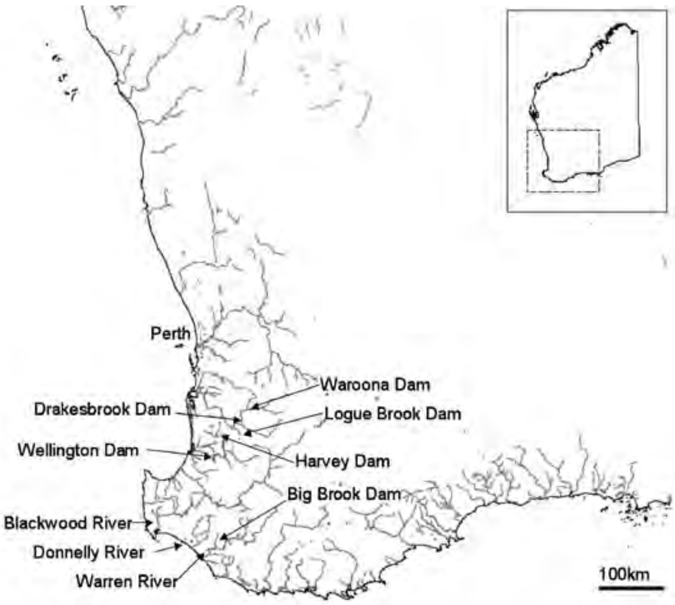

Figure 1. Location of rivers and dams sampled for predaceous fish in southwest WA.

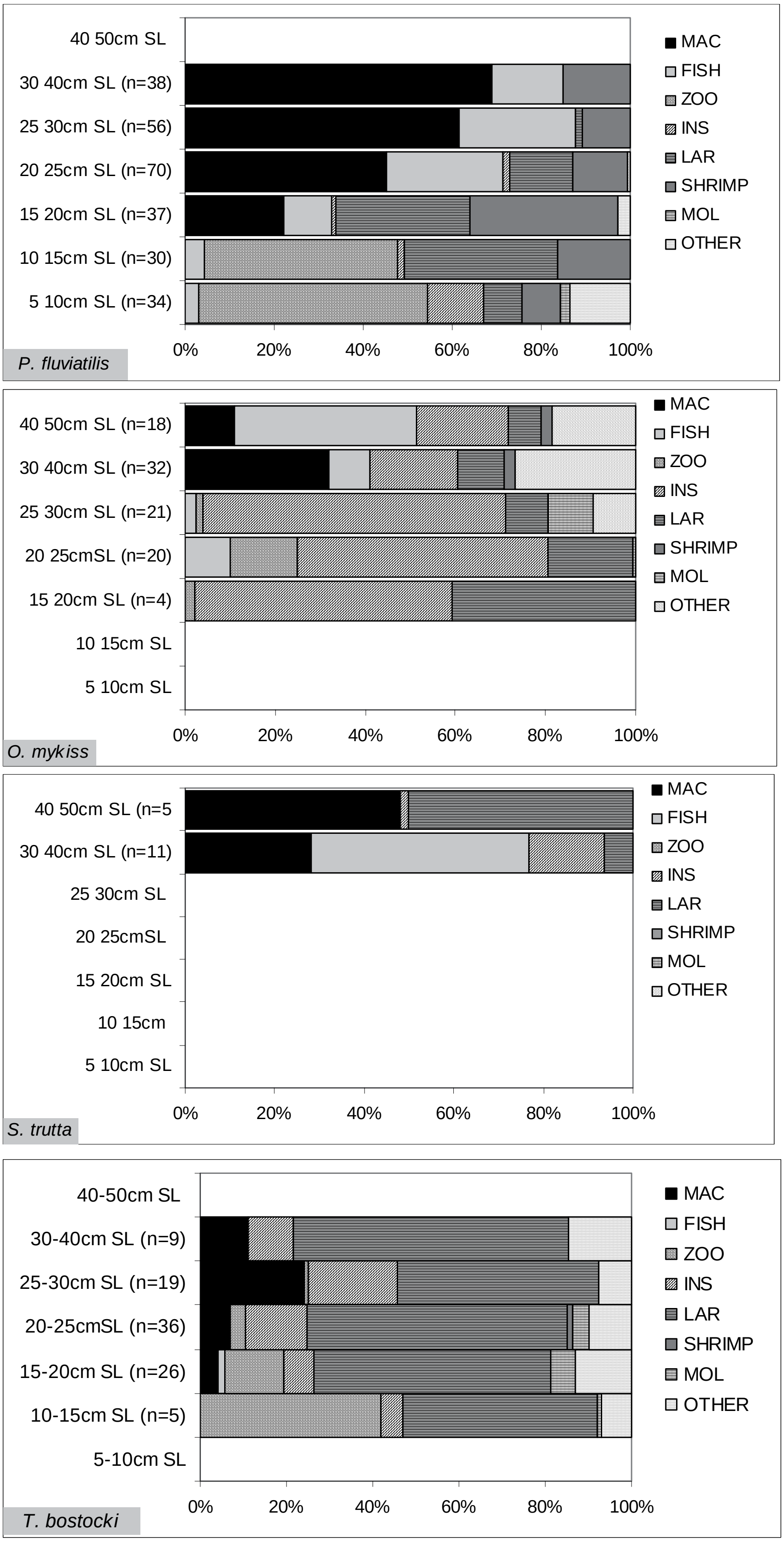

Figure 2. Ontogenetic changes in the dietary composition of *P. fluviatilis*, *O. mykiss*, *S. trutta* and *T. bostocki*.

a)

b)

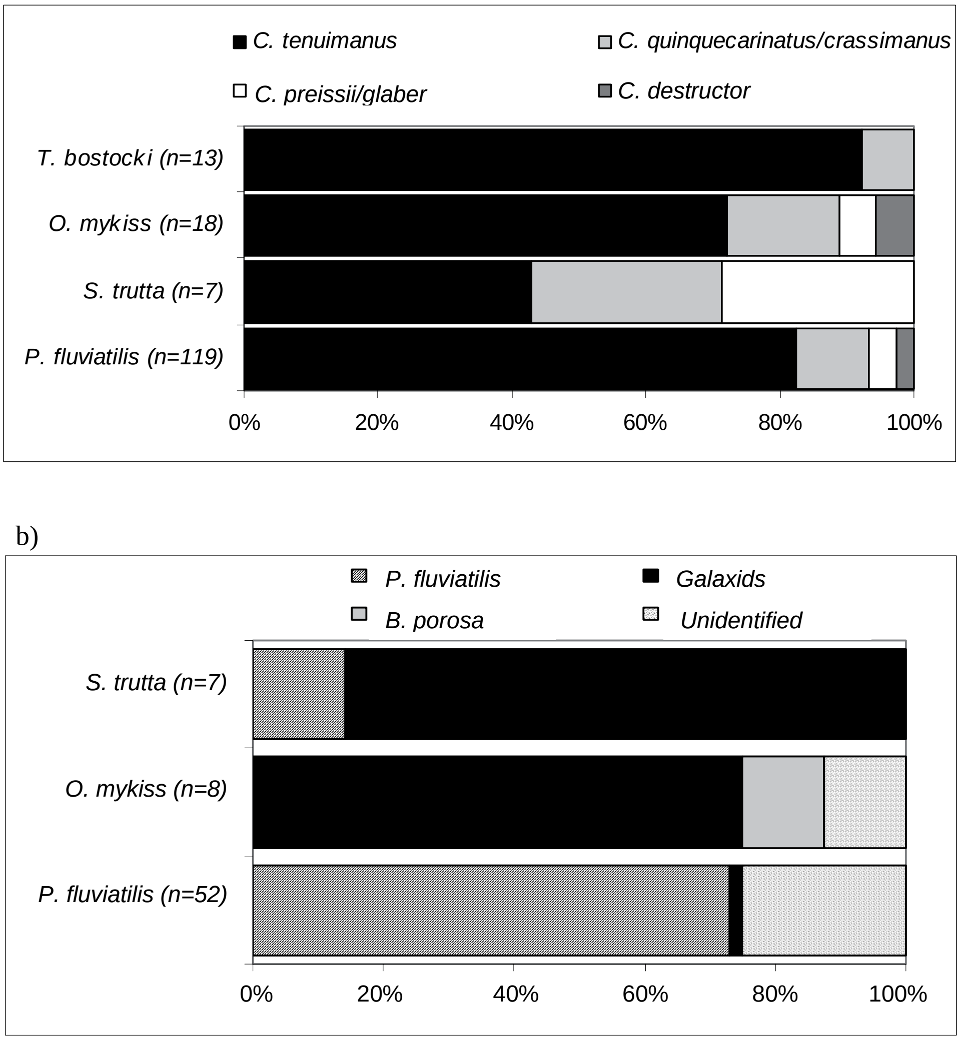

Figure 3. Freshwater crayfish (a) and finfish (b) species composition in the diet of *P. fluviatilis*, *O. mykiss*, *S. trutta* **and** *T. bostocki*.

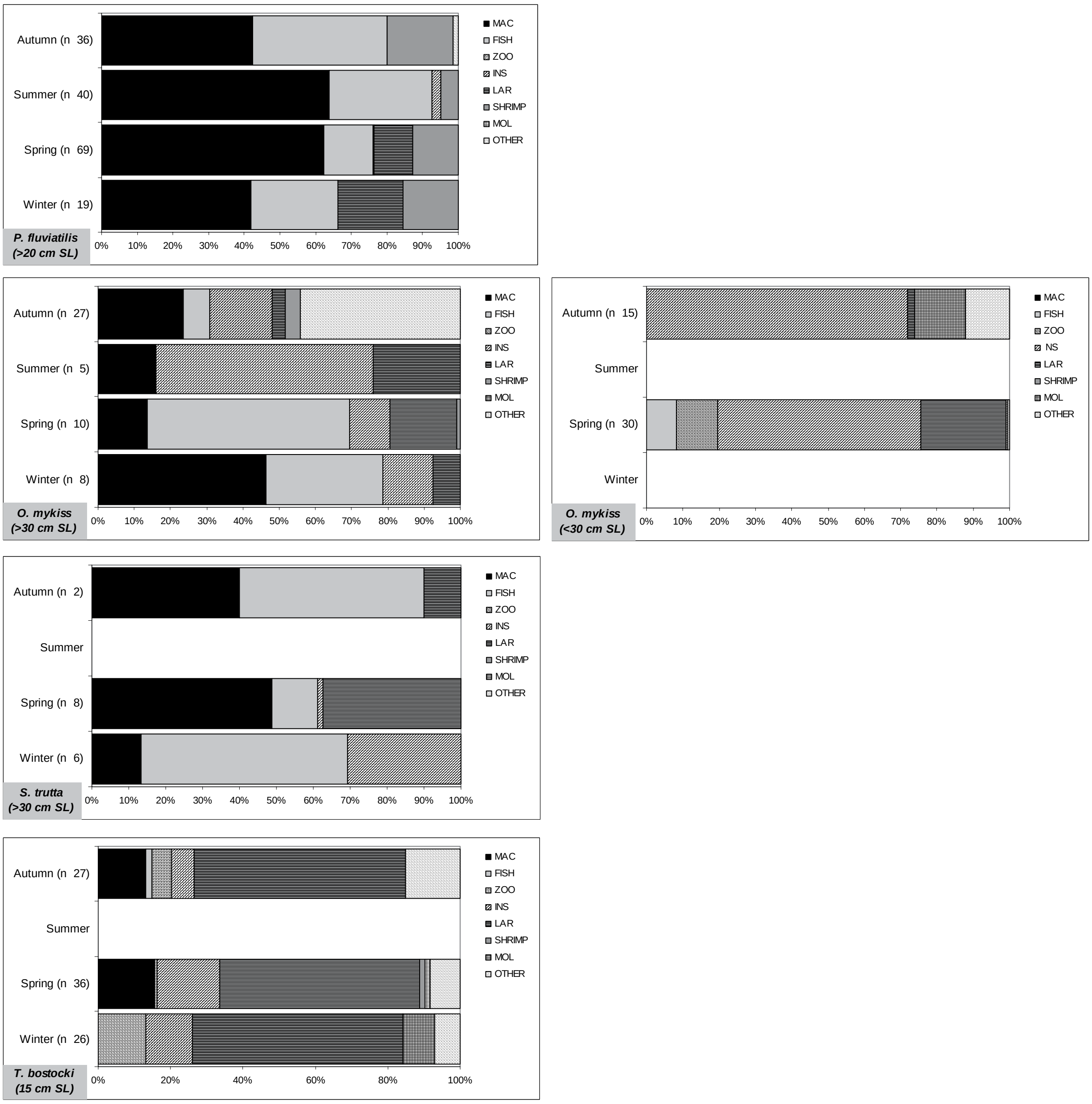

Figure 4. Seasonal changes in dietary composition of *P. fluviatilis*, *O. mykiss*, *S. trutta* and *T. bostocki*.

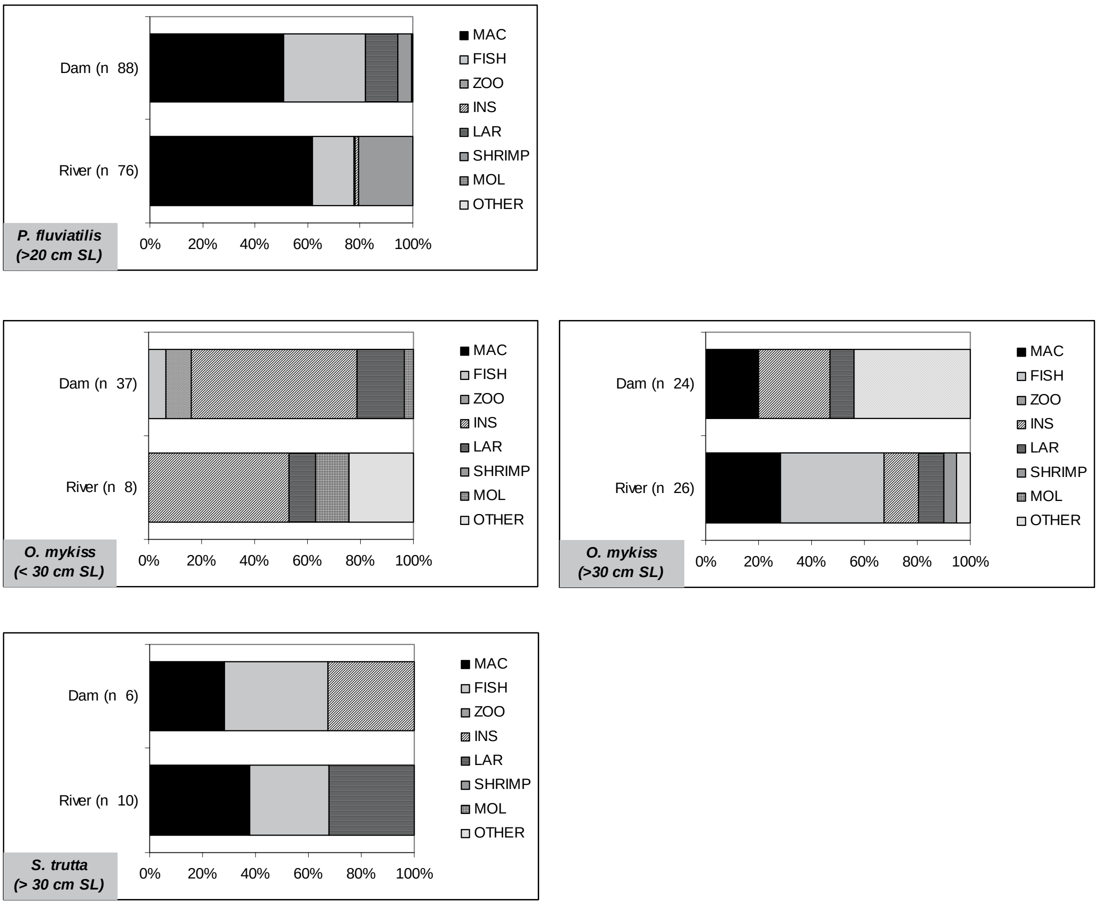

Figure 5. Spatial differences in dietary composition of *P. fluviatilis*, *O. mykiss*, and *S. trutta*.

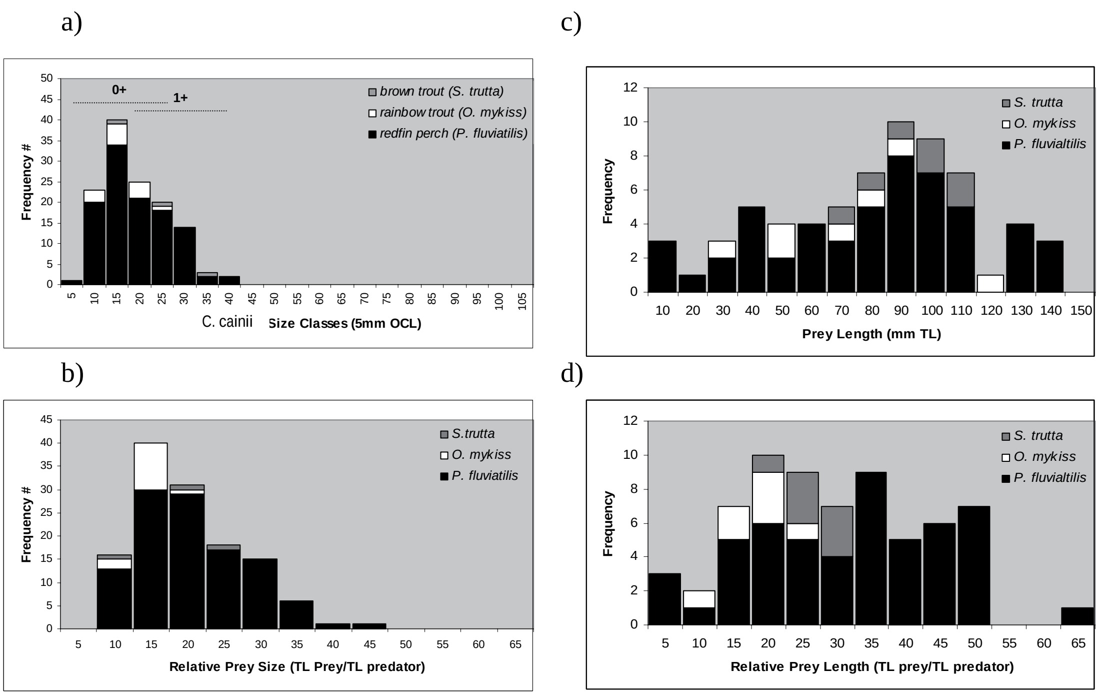

Figure 6. OCL and Length frequency distribution of absolute and relative length of *C. cainii* **(a and** b) and finfish ingested by *P. fluviatilis* **,** *O. mykiss* and *S. trutta* (c and d).

a)

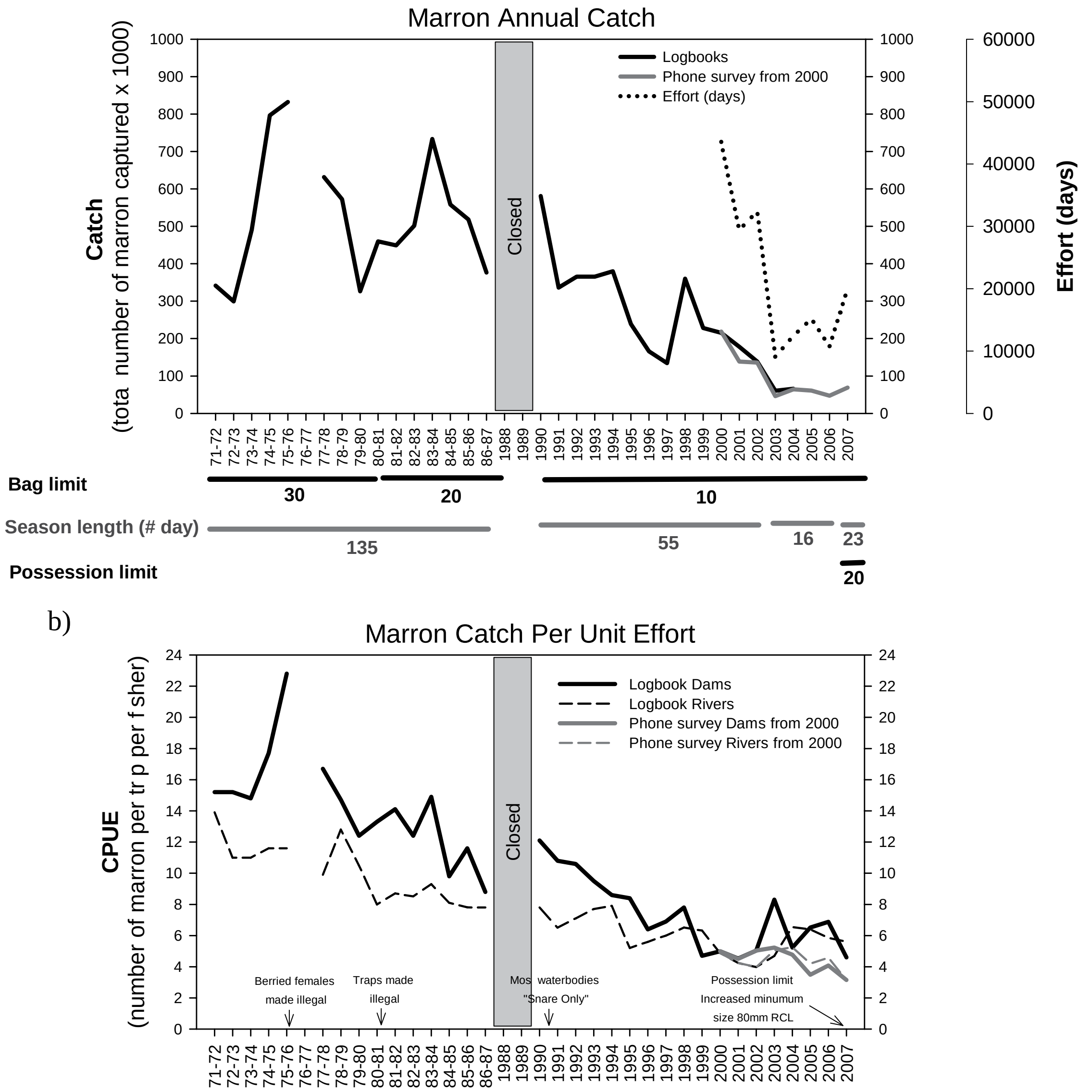

Figure 7. The estimated total catch (a) and catch per unit effort (b) of the Recreational Marron Fishery between 1971 and 2007.

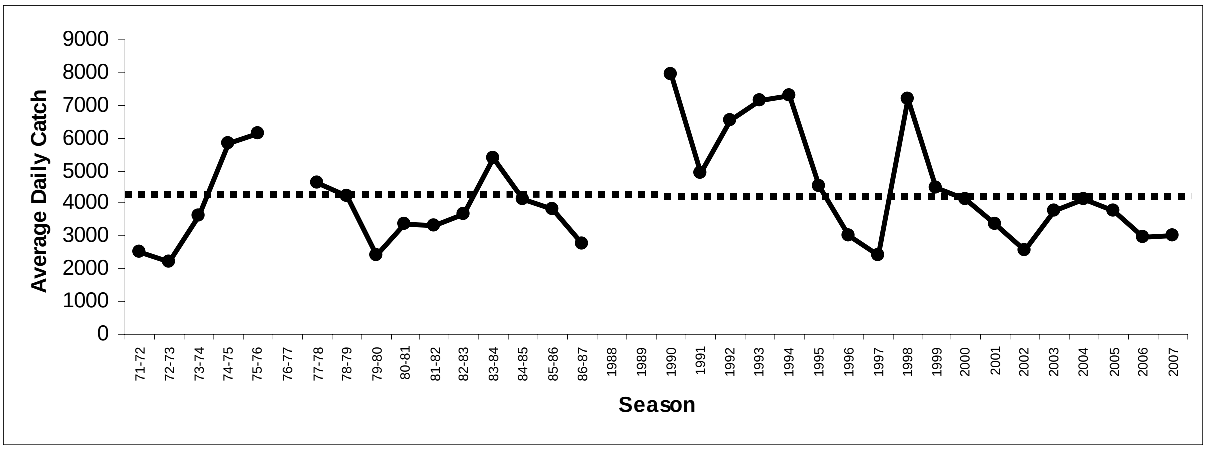

Figure 8. Annual variation in estimated average daily landings in the Recreational Marron Fishery between 1971 and 2007.

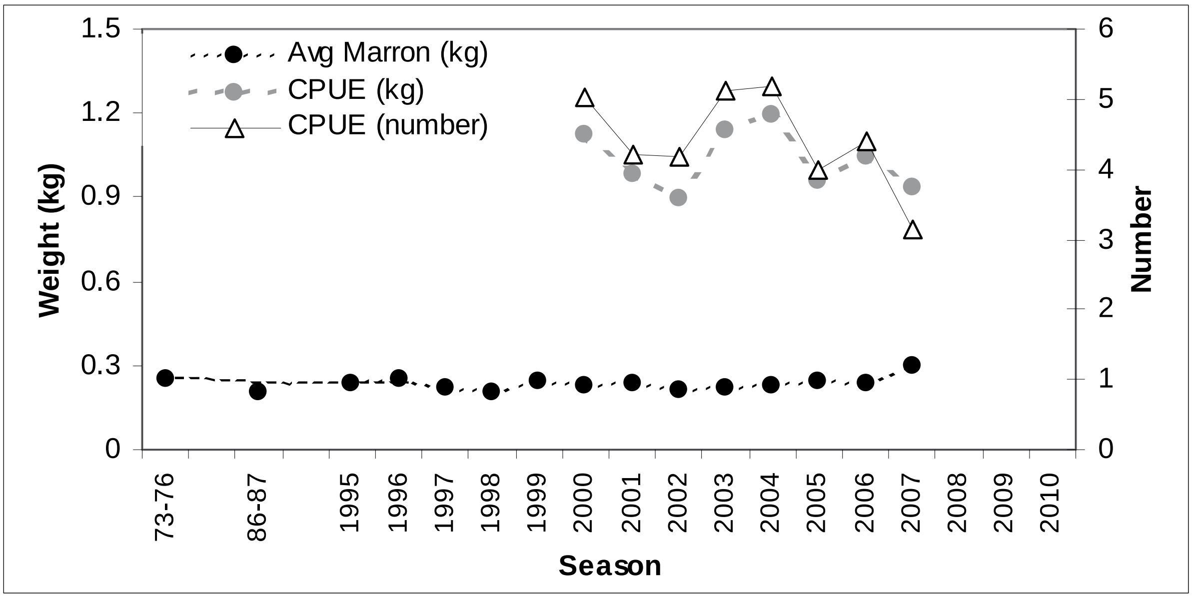

Figure 9. Annual variation in the estimated average weight of retained marron, CPUE (number) and CPUE (kg).

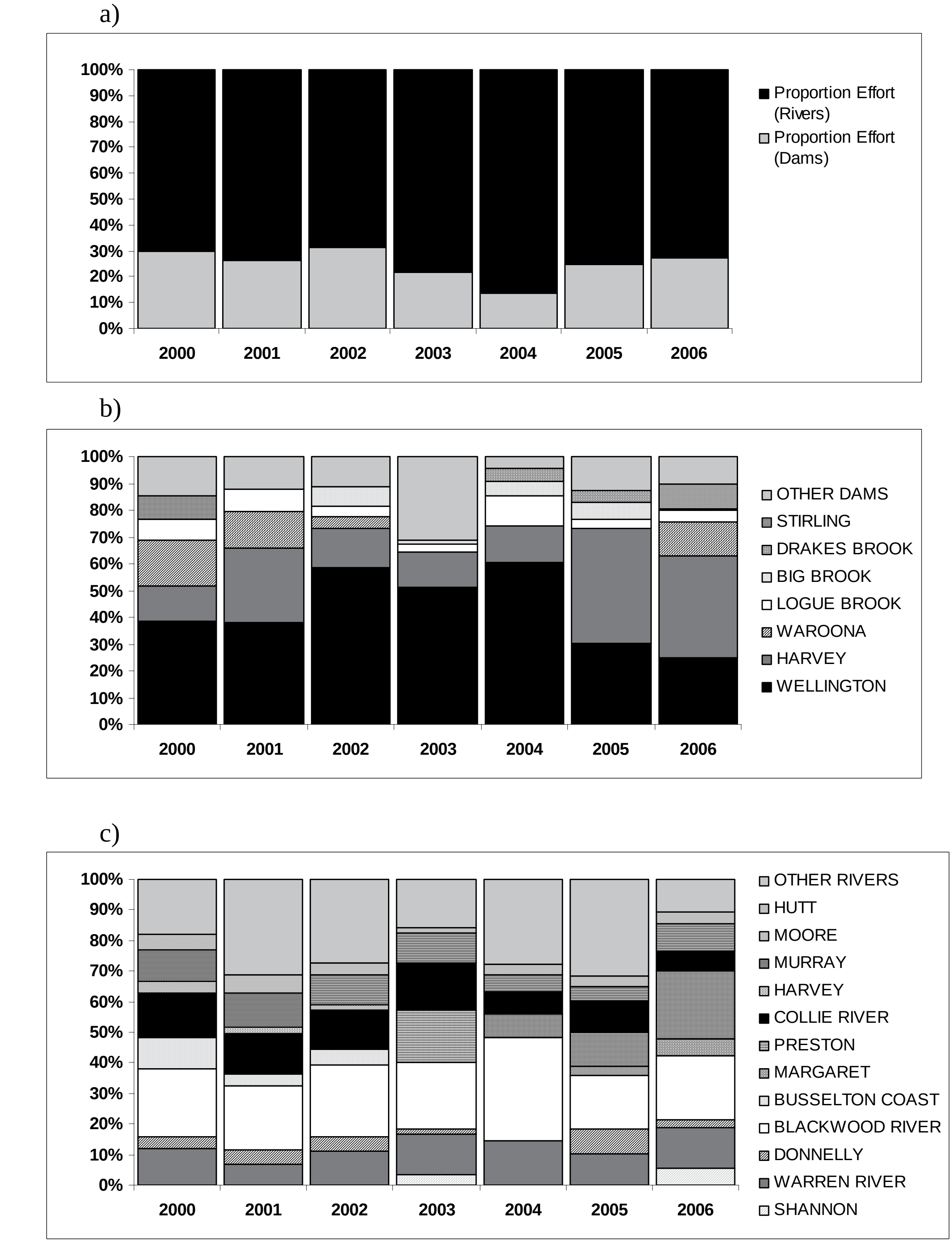

Figure 10. Annual variation in effort allocation between (a) rivers and dams, (b) among dams and (c) among rivers.

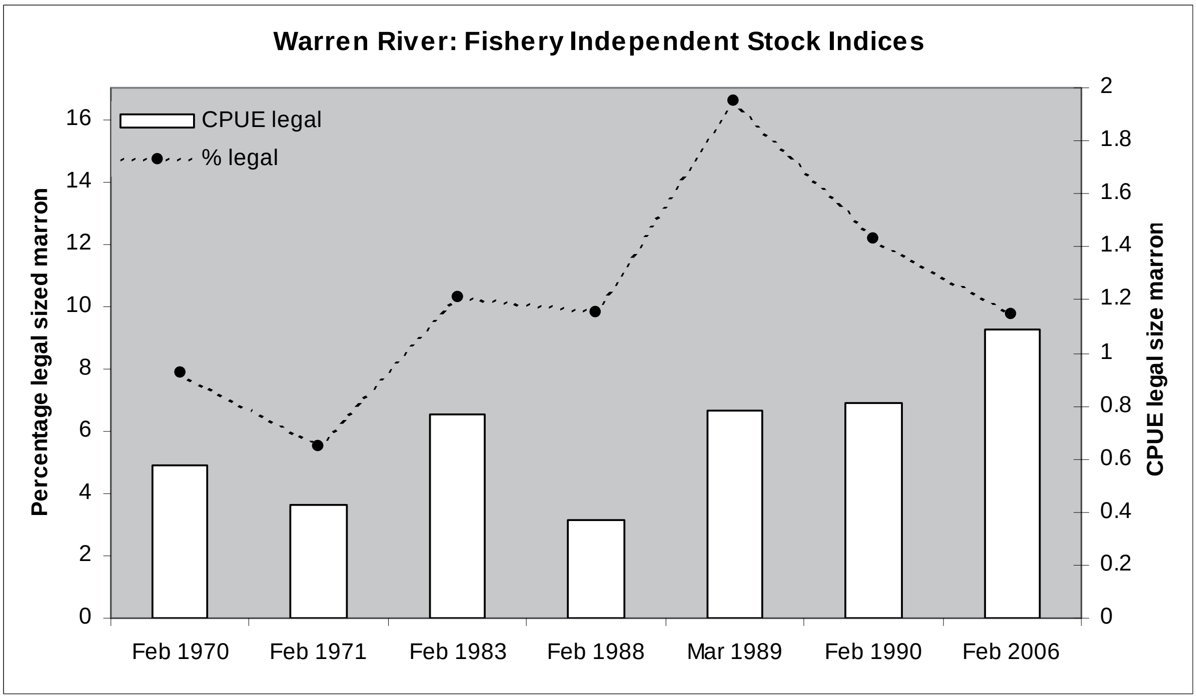

Figure 11. Development of fishery independent marron stock indices in the Warren River.

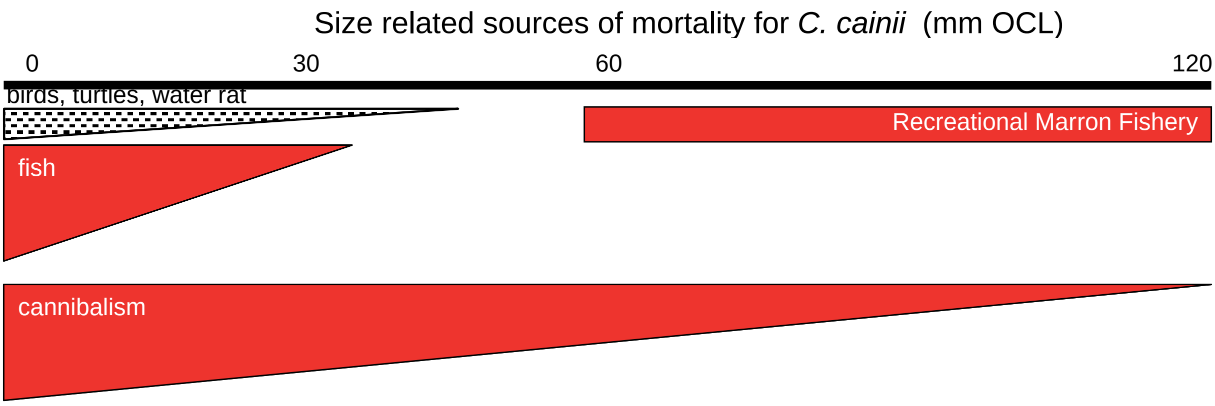

Figure 12. Schematic overview of likely impact of different sources of mortality for *C. cainii* (Note: the overall impact of birds, turtles and water rats on marron mortality is unclear).

5.0 Population biology of indicator marron stocks and implications for the sustainable management of the fishery

Stephen Beatty, Martin de Graaf, Brett Molony and Vinh Nguyen

5.1 Introduction

Aside from work in a number of systems in the 1970s (see Morrissy 1970, 1975), it is only recently that the population and reproductive biology of marron has been fully described in wild systems in this State (Beatty et al. 2003a, 2004, Chapter 6). These studies have revealed considerable differences in key biological parameters of the species between different systems and have revealed an extremely variable life history that is largely governed by environmental conditions. Quantifying these parameters in priority recreationally fished stocks is crucial to managing these fisheries sustainably. For example, the minimum legal size of Marron in the Hutt River was recently increased to 90 mm OCL as a result of research that found that the population was fast growing and matured at a much greater size than more southern populations in Waroona Dam (Beatty et al. 2004) and the Warren River (Morrissy 1975). This study has quantified the length of first maturity in other key systems (see Chapter 6) and has allowed more robust minimum size limits being set for the fisheries.

Similarly, considerable variations in the growth, mortality, survivorship and production probably exist between recreationally fished Marron populations and these variations have considerable implications for the ongoing sustainable management and monitoring of the fishery. In particular, major environmental differences in terms of habitat exist between the dam and river populations and these obvious differences are likely to translate into variability in key population biology parameters. For example, warmer environments and/or systems with greater productivity may increase growth rates thus increasing lengths at first maturity; as found in the northern Hutt River population (Beatty et al. 2004). Despite this potentially high variability, key population biology parameters such as growth, mortality, exploitation rates, abundance, density and productivity have previously only been determined for the Hutt River, at the northern-most point of its distribution in Western Australia (Beatty et al. 2004).

This study therefore aims to determine important population biological parameters of two recreationally fished Marron populations. These parameters include the growth, mortality, exploitation rate, survival rate, abundance, density and production in Wellington Dam and the Warren River. Management strategies and monitoring programs will also be identified for river and dam populations to develop models for predicting future catches and to ensure the sustainable management of the fishery.

5.2 Methodology

Sampling protocols

Sampling of Marron in Wellington Dam and the Warren River occurred on eight occasions between April 2005 and April 2006. An additional two opportunistic samples were carried out in September and October 2006 in order to recapture previously marked individuals. On each of the major sampling occasions, consistent effort of standardised trapping occurred, at Potter's Gorge in Wellington Dam (area 250 x 150 m) and at Heartbreak Trail (800 x 20 m) in the

Warren River, using box-traps as described in Chapter 7 (i.e. ~50 traps per sampling occasion). Marron only become trappable using standard marron traps at >35 mm OCL, therefore various other juvenile sampling techniques were employed in order to ensure a full size range of the populations were sampled for length frequency and modal progression analysis. These juvenile sampling techniques are detailed in Chapter 8 as part of the development of a standardised juvenile abundance sampling protocol. To further ensure adequate sampling of juveniles for growth estimates, supplementary hand scooping of juveniles also occurred on each sampling occasion from the bank of Wellington Dam and at two sites in Lefroy Brook, a tributary of the Warren River upstream of the Heartbreak Trail trapping site.

Each individual captured was sexed and measured to the nearest 1mm OCL. Individual coded marking occurred for those animals captured during the sampling occasions in June, August, October and December 2005. The marking was made on the ventral side of the four uropods (up to three punches per uropod, left to right) in the pattern of 1-2-4, 7-10-20, 40-70-100, 200-400-700. This marking technique was only carried out on larger >35 mm OCL animals (i.e. trappable with adequate uropod surface area) and allowed accurate identification of individuals following multiple moults during the study period. Subsequent recaptures were re-marked if they had moulted, to ensure continuation of identification.

Growth analysis

Modal progression in growth analysis of invertebrates and freshwater crayfishes in particular can prove difficult due to the problem of the overlapping of older cohorts. However, this methodology has recently been used in fitting growth curves on younger age classes of freshwater crayfish in southwestern Australia, including Marron (see Beatty et al. 2004, 2005a, b). The use of this technique for the analysis of the populations in Wellington Dam and within the Warren River will allow directly comparable results with those of Beatty et al. (2004) in the Hutt River Marron population. Conversely, individual mark-recapture of those younger (<35 mm OCL) cohorts via tail punching was not possible due to the small size of the telson and uropods. Therefore, both methods of growth determination were undertaken in order to fully describe and compare the growth of the populations in Wellington Dam and the Warren River. The complementary use of both modal progression analysis and mark-recapture for growth and the latter for population size estimation allowed determination of key population biology parameters, including total (Z) and fishing (F) mortality, annual survivorship (S), abundance (A), density (D) and production (P).

Modal progression

The techniques for modal progression analysis followed those of de Lestang et al. (2003) and Beatty et al. (2004, 2005a, b). September 1st was assigned as the birth (hatching) date because the main spawning period of *C. cainii* in the present study, occurred approximately between August and October 2005 as indicated by increase in the berry-up rate during the reproductive biology data collection period between May and December 2005 (Chapter 6). Sexes were pooled for analysis as initial examination of the sub-adult modes in the length-frequency distributions revealed no discernable differences between sexes. Single, two and three normal distributions were fitted to length-frequency distributions, in 2 mm OCL increments, on each sampling occasion in Wellington Dam and the Warren River with the most appropriate normal distributions for each month determined using the chi-square method (Schnute and Fournier 1980) with the modification described in de Lestang et al. (2003).

Once the modes were determined for each distribution in each month, the relative location of the OCL distribution of a cohort within the total frequency distribution of each month and the relationship of the OCL distribution in the adjacent months were used to assign the cohorts to 0+ or 1+ age classes (de Lestang et al. 2003). The moult frequency of freshwater crayfish is greatest in the first few months of life (Reynolds 2002). Therefore a modified version of the von Bertalanffy growth curve of Hanumara and Hoenig (1987) was fitted to the mean OCL distributions that assumed that the maximum growth rate occurred in <~5 months (de Lestang et al. 2003):

$$OCL_t = \begin{cases} OCL_\infty\left\{1-\exp\left[-\left\{\frac{K(t-t'_0)}{12}+\frac{CK}{2\pi}\sin 2\pi\frac{(3)}{12}\right\}\right]\right\} & \text{if } t < t_s + 3 \\ OCL_\infty\left\{1-\exp\left[-\left\{\frac{K(t-t'_0)}{12}+\frac{CK}{2\pi}\sin 2\pi\frac{(t-t_s)}{12}\right\}\right]\right\} & \text{if } t > t_s + 3 \end{cases}$$

where OCL_t is the estimate of orbital carapace length at age t months, OCL_∞ is the asymptotic orbital carapace length, K is the curvature parameter, t_0 is the theoretical age at which the estimated orbital carapace length is zero ($t_0 = t'_0 - (6C/\pi)\sin(0.5\pi)$), C is the relative amplitude of the seasonal oscillation (where $0 < C < 1$) and t_s is the phase of seasonal oscillation relative to t_0 Growth curves were fitted to the length-frequency data using Solver in Microsoft Excel™.

Mark-recapture

The mark recapture program was undertaken between June and December 2005 with subsequent sampling for recaptures in March, May and October 2006 The sampling regime allowed both an analysis of growth of the larger cohorts of trappable Marron (>~35 mm OCL) and also an estimation of trappable population abundance and density (see next section). Growth trajectories were plotted for each individual male and female Marron recaptured in the Warren River and Wellington Dam Mean absolute growth (G_{abs} mm OCLyr^{-1}) and relative growth (G_{rel} % OCLyr^{-1}) rates were calculated for recaptured males and females (and pooled for sexes) in both systems. The statistical significance of any differences observed between these growth rates were tested first by employing Levene's tests for equality of error variance on the un-transformed data. Heteroscedastic data were ln-transformed prior to one-way ANOVAs being performed. A probability level of ($\infty = 0.05$) was used to test all null hypotheses that the growth rates were not different between sexes and sites.

To provide direct comparison betwe n the growth as determined from modal progression analysis of the sub-adult size classes (described above for each system) with those trappabl animals in the mark-recapture program, Gulland and Holt (1959) estimates of von Bertala ffy parameters L_∞ and K were initially undertaken for each sex individually, and pooled sexes, in each system of recaptured, trappable animals using the equation:

$$(\Delta OCL/\Delta t) = a + bOCL_m$$

Where $\triangle OCL$ is the change in the OCL during the time at liberty $\triangle t$ and OCL_m is the mean OCL during $\triangle t$. The parameter a is the y-axis intercept and b is the slope of the regression and –b is equal to K and –a/b is equal to OCL_∞. However, this analysis resulted in a positive slope of the regression line as no clear reduction in growth rate occurred with increasing size in the Warren River. Therefore, forced Gulland and Holt plots whereby the length of infinity was implied by the size class of the largest Marron captured in both systems (i.e. 105 and 78 mm OCL in Warren River and Wellington Dam, respectively) and the mean of the absolute growth rates (G_{abs}) (i.e. y axis) and mean size (i.e. x axis) were used to determine K using the equation:

$$K = \overline{Y} / (L_\infty - \overline{X})$$

The moult increments of Marron in the Warren River and in Wellington Dam were determined by examination of the modal frequencies of absolute growth rates of individuals within 10 mm size classes. The most appropriate best fitting normal distributions were fitted to the dominant mode using the same technique as applied in the above modal progression analysis for growth rates of sub-adults. The first (dominant) mode reflected a single growth increment with those subsequent (i.e. larger) modes representing those individuals that had moulted more than once (Frisch, 2007). The average time at liberty of those marron that had moulted once as determined from the modal analysis was determined for each 10 mm category of Marron in both systems. (Robertson & Butler, 2003).

Abundance and density estimates

The above mentioned multiple mark-recapture program was used in estimating the trappable population size of Marron from the trapped section of the Warren River and the Wellington Dam. The major assumptions were that marked individuals were evenly distributed over the trapping area (this was assumed to be met as the multiple marking efforts occurred evenly over the trapping areas) and no net change in the trappable population occurred during the census period due to emigration, immigration, recruitment or mortality. These latter assumptions may not have strictly been adhered to However, the Warren River section was effectively a closed area (~16000m^2) due to the presence of two rock bar barriers at the upstream and downstream points of the trapped area and Marron are believed to have relatively high home range fidelity (Morrissy 1975) which would have limited the movement of animals into and out of the trapped area (~37500m^2) in Wellington Dam. Furthermore, both areas were effectively totally blanket trapped on each occasion (traps set within ~20 m from each other assuming a bait attraction of ~300 m^2, see Chapter 7 and Morrissy 1975) using identical sampling techniques and effort.

For determination of trappable population abundance and densities, marking of Marron occurred in June, August, October and December 2005 with additional sampling for recaptures occurring in March and May 2006 The Schnabel formula (Ricker, 1975) was used that allowed population estimation based on multiple marking occasions. The formula is:

$$N = \left[\frac{\sum (CiMi)}{R + 1} \right]$$

where N is the population size estimate at the end of the previous sampling occasion, C_i is the number captured during the period i, M_i is the number of marked individuals at the beginning of sampling period i and R is the total recaptures during all sampling occasions.

The density (D m^{-2}) of the trappable population in each sampling region in the Warren River and in Wellington Dam was determined using the formula:

$$D = N / A$$

where N is the estimated trappable population in the section from the Schnabel formula and A is the approximate area of the trapped section in each systems, as estimated from aerial photography (*Google Earth*™).

Productivity

The mean stock productivity (P g.m^{-2}yr^{-1}) of trappable (i.e. ~>35 mm OCL) Marron of both sexes in the Warren River a d in Wellingto Dam was estimated using the formula::

$$P = G_{wt} x D$$

where G_{wt} is the mean annual weight gain for each sex in each system determined by converting G_{abs} to weight (using the previously determined length-weight relationship of Marron in Beatty et al. (2003a)) and D is the mean density of trappable females and males in each system.

Mortality

To determine the instantaneous mortality rate (Z, 1yr^{-1}), a catch curve was employed that plotted the natural logarithms of numbers of Marron surviving over age (Beverton and Holt, 1957; Ricker, 1975) using the growth parameters estimated from the forced Gulland and Holt plots that better represented the growth rates of the larger cohorts (approximating those that were trappable) in the population. In order to provide an estimate of rates of fishing and natural mortality in the Warren River and in Wellington Dam, estimates of Z were determined from the catch curves separately for size classes that were unexploited (i.e., $\underline{Z}_u$, an estimate of natural mortality) by recreational fishing (i.e., those <76 mm carapace length, or < 54.2 mm OCL (Beatty et al. 2003a)) and those open to legal fishing (i.e. $\underline{Z}_e$, > 54.2 mm OCL, an estimate of total mortality). These estimates assumed negligible illegal retention of undersize individuals. As length-frequency data precluded accurately identifying frequency at age for older animals, the data were used to create an age-frequency distribution via the generation of a length-converted catch curve (Pauly 1983; King 1995):

$$\ln\left[\frac{N\mathrm{i}}{\Delta t}\right] = \alpha - Zti$$

where N_i is the number of individuals in a size class, $\triangle t$ the time taken to grow through the size class i, t_i is the relative age of the size class i (t_0 = 0 as only relative ages are required), α is a constant, and Z is either the total rate of instantaneous total mortality of those that were not subject to recreational fishing (Z_u 1yr^{-1}) or those that were exploited (Z_e, 1yr^{-1}). The annual percentage survivorship (S) of fully exploited Marron was then determined using the equation:

$$S = 100 \text{ x } \exp(-Z_e)$$

Subsequently, the inst taneous rate of fishing mortality (F, 1year^{-1}) was determined using modified versions (i.e , using the estimate of $\underline{Z}_e$ and $\underline{Z}_u$) of the King (1995) equation:

$$F = Z_e - Z_u$$

An estimate of the exploitation rate (E the proportion of Z_e attributed to fishing mortality) was then determined using modified versions of the Quinn and Deriso (1999) equation:

$$E = \frac{F}{Z_e}$$

5.3 Results

Growth

A total of 5308 and 5117 Marron were captured in the Warren River and in Wellington Dam, respectively over a period of 18 months. Of these, 3847 and 3229 were captured in the standardised box-trapping programs that were used in the multiple mark-recapture analysis of growth, mortality and production. The remainder were sub-adults captured during the trialling of methods to determine juvenile abundance and were included in the modal progression analysis of growth. The sex ratio (female:male) of those captured in the standardised trapping program was 1:1.52 and 1:1.95 in the Warren River and Wellington Dam, respectively.

Examination of the length-frequency distributions in the Warren River and Wellington Dam populations and from fitting normal distributions, revealed a clearly discernable single 0+ cohort between April and December 2005; that became 1+ in February 2006 (Fig. 1). A new 0+ cohort, the result of spawning in spring 2005 (as mentioned, September 1st the estimate birth date), was first discernable in February 2006 and then again in April 2006. Considerable overlap in the larger size cohorts prevented fitting normal distributions to those sizes >~40mm OCL. The seasonal von Bertalanffy growth curves fitted to the monthly modes of the 0+ and 1+ size classes (up to the age of 19 months) in the Warren River and in Wellington Dam clearly indicated a faster growth rate of those sub-adult animals in Wellington Dam compared to the Warren River (Fig. 2, Table 1). This was highlighted by a growth coefficient (K) of 0.32.year^{-1} *cf* 0.23.year^{-1} in Wellington Dam and the Warren River, respectively (Table 1). The northern Hutt River population had the greatest rate of growth with a K of 0.42.year^{-1} and the largest OCL_{∞} of 101.9 mm. Based on extrapolation of the seasonal von Bertalanffy curve of sub-adult growth, the time taken to reach the current legal size of 80 mm CL (~57 mm OCL) would be ~75 and ~42 months in the Warren River and in Wellington Dam, respectively (Table1). This compares with only ~25 months for the Hutt River.

During the multiple-mark recapture program of trappable (>~40 mm OCL) adult marron, a total of 1172 and 1039 were marked in the Warren River and Wellington Dam respectively. Recapture rates were similar in both systems (39.8 and 36.1%) with a greater percentage of males being recaptured in both systems (probably due to a degree of trap shyness of berried females coupled with higher aggression by males) (Table 2). The multiple mark recapture program in these systems revealed an opposite trend in growth rates to those revealed in the modal progression analysis of sub-adult marron, with the Warren River marron growing significantly faster than those in Wellington Dam (Figs. 3 and 4). The average size of marron re-captured in the trapping program in Warren River (61.9 ±0.54 mm OCL) was significantly greater than those in Wellington Dam (51.9 ± 0.29 mm OCL) (Fig. 5, Table 2). The greater growth rate of the trappable Warren River population was evidenced by the significantly greater overall absolute growth (mm.yr^{-1}) of females, males and pooled sexes when compared to those in Wellington Dam (Fig. 5). Similarly, the relative growth rate (%OCLyr^{-1}) of females, males and pooled sexes was also significantly greater in the Warren River population (Fig. 5).

Figure 6 shows the mean absolute annual growth rate of 10 mm OCL size categories and reveals that the growth rate slowed with increasing size in Wellington Dam, however, this trend was not observed in the Warren River. A similar trend in declining relative growth rate with size occurred in Wellington Dam (Fig. 7), and a sharp decline in the relative annual growth occurred in the Warren River between 30-40 mm OCL and the larger size categories, with a slight negative trend occurring in the subsequent larger sizes.

The expected slowing of growth with size of trappable animals in the Warren River, did not occur with positive relationships between mean OCL and absolute annual growth rate of both sexes (Fig. 8). This prevented the estimation of K and OCL_∞ using the unforced plots. A negative relationship between mean OCL and absolute annual growth rate was observed for both sexes in Wellington Dam with the estimation (pooled sexes) of K being 0.086.year^{-1} and OCL_∞ 84.3 mm (Fig. 9). The subsequent forced Gulland and Holt formula estimated the K in these systems as 0.14.year^{-1} and 0.11.year^{-1} using specified OCL_∞ of 105 and 78 mm OCL in the Warren River and in Wellington Dam, respectively (Table 2).

The relationships between the relative growth rate and the mean OCL of marron in the Warren River and Wellington Dam are shown in Fig.s 10 and 11. The relative growth rate clearly decreased with size in Wellington Dam with a weaker negative relationship existing in both sexes in the Warren River.

The frequency of absolute growth increments are shown in Fig. 11 and the subsequent modes of these increments are plotted in Fig. 12. The moult increments of these 10 mm size categories of marron in the Warren River and in Wellington Dam clearly show that a greater moult increment occurred in the 40-50 and 50-60 mm OCL size classes in the Warren River (3.34 and 4.02 mm OCL, respectively) compared to Wellington Dam (3.18 and 3.50, respectively). A lack of marron >60 mm OCL in Wellington Dam prevented determining their moult increments, however, those categories in the Warren River showed an increase in moult increment to 5.89 mm OCL in the 80-90 mm size category (Fig. 11). There was no clear differences in the mean time at liberty of Marron that moulted once in each system in the 40-50 and 50-60 mm OCL size categories with mean time in the Warren River being 0.69 and 0.75 yrs *cf* 0.66 and 0.76 respectively (Fig. 12). Therefore in both systems, a slight increase in the average time at liberty occurred between the 40-50 and 50-60 mm OCL size categories in those marron that had moulted once.

Abundance, density and productivity

Based on the multiple mark recapture program and the subsequent Schnabel formula, the population estimate of females and males in the trapped area in each system were 2643 and 4355 in the Warren River (ratio of 1:1.65) and 2350:2346 (1:0.998) in Wellington Dam. Therefore, although the sex ratio of overall recaptures in the Warren River (i.e. 1:1.52) was similar to that determined by the Schnabel formula, the parity in sex ratios suggested by the Schnabel formula in Wellington Dam, differed markedly from that found by overall re-capture ratios with a far greater proportion of males observed in the latter estimate (i.e. 1:1.95).

The overall density of marron in the Warren River was much higher (0.17 and 0.27 m^{-2} for females and males, respectively) than in Wellington Dam (0.06 m^{-2} for both sexes). The subsequent estimates of Marron productivity were much greater for the Warren River (17.2 and 19.8 g.m^{-2}.yr^{-1} for females and males, respectively) than Wellington Dam (1.63 and 1.67 g.m^{-2}.yr^{-1} for females and males, respectively).

Mortality

The instantaneous total rate of mortality ($\underline{Z}_e$) of fully recruited marron (based on the catch curves and pooled sexes) in the Warren River was slightly higher than that recorded in Wellington Dam (0.59 and 0.47 yr^{-1} respectively, Table 1). However, the northern Hutt River population had a much greater Z_e of 1.79yr^{-1}. The unexploited (i.e. pre-legal size) mortality (Z_u) in the Warren River was considerably higher than that recorded in Wellington Dam (0.42 and 0.18 yr^{-1}) and this resulted in a greater fishing mortality (F) being calculated for Wellington Dam (0.29 yr^{-})

than in the Warren River (0.17 yr^{-1}). Therefore, the exploitation rate (*E*) was much greater in Wellington Dam (0.62) than in the Warren River (0.29). These rates were much lower than those calculated for the Hutt River population with *F* and *E* being 1.38 yr^{-1} and 0.77, respectively. The annual survivorship of fully recruited and exploited (legal size) marron in the Wellington Dam was 62% compared with 55% in Warren River and only 17% in the Hutt River.

5.4 Discussion

The modal progression analyses clearly showed a more rapid growth rate of sub-adult marron in Wellington Dam compared with that of the Warren River (Table 1, Figs. 1 and 2). However, the multiple mark recapture program revealed that the rates of growth of larger, trappable (>~40 mm OCL) individuals, were actually considerably greater in the Warren River than Wellington Dam (Table 2, Figs. 3-6). The modal progression of marron in the Hutt River was more clearly discernable than those in the current study (up to 27 months *cf* 19 months), mainly because a much greater continued growth rate of sub-adults was recorded in the northern river population with *K* being 0.42. $year^{-1}$, allowing individual cohorts to be discernable at older age classes. This rapid growth rate in the latter population probably also resulted in the relative large L_{50} of 70 mm OCL for females compared with ~37 and ~39 mm OCL in the Warren River and Wellington Dam populations, respectively (Chapter 6). The higher densities (0.44 versus 0.11 m^{-2}) and greater mean annual weight gain in adults (83.9 ±4.6 versus 26.4 ±2.1 $g.yr^{-1}$) resulted in much greater productivity in the Warren River (based on trappable populations) compared to Wellington Dam (Table 2).

There were also marked differences in the mortality, exploitation and survivorships in these systems. Specifically, a higher total mortality (Z_e) was recorded in the Hutt River (1.79 yr^{-1}) than in both the Warren River (0.59 yr^{-1}) and Wellington Dam (0.47 yr^{-1}) and this resulted in far lower annual survivorship of marron in the Hutt River compared with the Warren River and Wellington Dam. Furthermore, fishing mortality and exploitation rate was also far greater in the Hutt River than in the other systems. However, fishing mortality and exploitation rate in Wellington Dam was considerably greater than that recorded for the Warren River (*E* of 0.62 versus 0.29, respectively). This high fishing mortality reflects that this system accounts for ~60% of the total annual dam effort (15-20% of overall effort). It should be noted that defining the area of sampling was far easier in the Warren River with the trapping regime effectively sampling a ‘closed’ area in that system whereas, due to the geomorphology of the Wellington Dam, precisely defining the sampling area in that system was based on an assumed high site fidelity of those in the trapped area.

These results suggest that the paucity of larger, legal sized marron captured in Wellington Dam may be a result of a combination of stunting of growth in the larger individuals, coupled with a greater level of fishing mortality. Conversely, it appears that the population in the Warren River has a consistent growth rate throughout the size cohorts and an overall similar total mortality to Wellington Dam, but has however, a relatively low exploitation rate. The differences in exploitation rates is undoubtedly related to the much higher degree of fisher bank access in the Wellington Dam (~100%) compared to the more difficult bank access in the Warren River (due to intact riparian vegetation). The relatively low level of fishing mortality in the Warren River, coupled with the high productivity (due to high densities and growth rate) compared with Wellington Dam, resulted in the capture of a considerable number of legal-sized marron in the Warren River during this study (Fig. 1).

The Hutt River population, on the other hand had both high growth rates and very high fishing mortality and exploitation (Table 1). Breeding females were not actually protected from fishing prior to reaching maturity during that study. Despite the high fishing mortality and lack of brood-stock protection, a considerable proportion of legal sized marron were captured during that particular study and Hutt River continues to support a recreational fishery. The high productivity of Marron in the river systems may be due, in part, to differences in food availability. For example, a consistent supply of allochthonous organic matter from the riparian zones of rivers may support higher growth rates in these systems compared to more seasonal autochthonous organic matter input in reservoirs.

The differences in the moult increment between the Warren River and Wellington Dam populations (Figs. 12 and 13) accounts for the differences in adult growth rates. The growth of Marron in Wellington Dam was previously described by Morrissy (1975) and the size of individuals at approximately 14 months of age (November) was found to be 34 mm OCL; which is considerably greater than that recorded in the current study (~21 mm OCL, Fig. 2) and suggests that growth rate is declining. Length at age was similar to that recorded by Beatty et al. (2004) in the fast growing Hutt River population of 33 mm OCL. Furthermore, Morrissy (1970) recorded a growth coefficient *K* of 0.2 for the Warren River population, similar to the 0.23 recorded by modal progression analysis in the current study. This suggests that there are both spatial (and probably temporal, due to interannual variability in environmental conditions; particularly rainfall and discharge (see Chapter 3) variations in growth rates of populations in the Marron fishery. This has implications for monitoring programs that need to incorporate both spatial and temporal scales (i.e. ongoing monitoring of key population parameters in a number of key stocks).

Growth rates of freshwater crayfish are known to be positively correlated with temperature (e.g., Jones, 1981; Jussila and Evans, 1996; Whitmore and Huryn, 1999). For example, *Paranephrops planifrons* grew faster in warmer pasture streams compared with cooler forested streams due to a greater moult increment and also a higher moult frequency of smaller individuals in the pasture streams (Parkyn et al., 2002). The greater growth rate in the Hutt River population than the others during this study would undoubtedly be linked to the higher temperatures experienced by this northern population; often around the optimum temperature for growth of marron of (24 C). Therefore, based solely on temperature regime, the growth rate in the Hutt River would have been expected to be greater than those estimated in populations examined in higher latitudes (corresponding to lower water temperatures) in this study and by Morrissy (1975). Furthermore, in the more northerly Wellington Dam population we would expect a greater growth rate than experienced in the southern Warren River population. The Hutt River population was found to have a greater growth rate than the majority of the more southern river and dam populations examined by Morrissy (1975), however, it was less than the rate recorded in the Harvey Dam. Moreover, although the Wellington Dam population grew faster early in life, this was reversed in adults.

Growth rates of these marron populations are not linearly related to temperature regimes because more complex factors are involved. A key factor would be the trade-off between growth and reproduction with food availability. Regardless of temperature, rapid growth rates would only be able to be achieved if adequate energy sources are available to support them. For example, a cooler habitat with complex habitat and high degree of food availability may allow greater growth rates compared with a warmer, habitat limited environment with more competition for food resources. Therefore, although dams may have large areas of shallow, warmer habitat, they have low habitat diversity (little or no riparian vegetation inputs) and food webs that perhaps have limited autochthonous production. Therefore, the growth rates of wild Marron populations are influenced by complex relationships between physical and ecological environmental factors.

Wellington Dam has a paucity of hide habitat, which is typical of the recreationally fished dams (Beatty et al. 2003b). However, one anomaly in terms of biological parameters would be the Harvey Dam marron population as it is believed to have an exceptionally high growth rate (possibly a result of high productivity due to nutrient inputs from recently flooded farmland), reflected by a greater minimum legal size of 90 mm OCL and its 'trophy fishery' status. Nonetheless, the management implications for reservoirs would be applicable to all recreationally fished reservoirs in the region (see below and section on Management Implications). The presence of large introduced teleost predators (see Chapter 4) in these habitat limited reservoir environments probably results both in the selection of faster growing juveniles that are able to attain a size that precludes inter and intra-specific predation, and a reduction in the density of the adult population as a result of lowered juvenile recruitment (Table 2). Additionally, as these systems generally have a lack of complex habitat, very little primary productivity, and negligible allochthonous input (due to a lack of bank exposure), they are likely to be food limited thereby stunting the growth of adult marron and reducing the carrying capacity of the systems resulting in the very low productivity observed in Wellington Dam (Table 2, Figs. 3 – 12).

The importance of hide habitat for marron productivity was highlighted by the artificial habitat study by Molony and Bird (2005). The study showed that marron (including newly recruited individuals rapidly populated artificial habitats in Big Brook Dam. This colonisation effectively increased productivity probably via a reduction of teleost predation. Furthermore, increasing the complexity of habitat in this system was also thought to enhance the biofilm community and thus total species richness of the system (Molony and Bird 2005). Those results, coupled with the findings of the current study, have direct management implications for enhancing the productivity of the fishery in similar reservoirs (see Management Implications).

The ease of bank access to fishing, the lack of hide habitat, and limited food availability may also result in the increased fishing mortality and exploitation rates recorded in Wellington Dam. Furthermore, this high exploitation rate may be removing those faster growing individuals thus selecting for slower growing adults; further contributing to the stunting of the population. Therefore, paucity of habitat probably leads to increased natural mortality via predation that would reduce subsequent adult densities, and food limitations coupled with high exploitation rates (selecting for slower growing Marron) may contribute to the relatively slow adult growth rates. These factors have likely resulted in the relatively low marron productivity and reduced the annual rate of recruitment to the fishery in Wellington Dam and may also be the case in other reservoir populations (Table 2).

It may be useful to consider the populations in the Wellington Dam as an indicator of reservoir populations, while the Warren River would be typical of an undisturbed river Marron population. However, the expression of biological plasticity (this study and Beatty et al. 2003; Beatty et al. 2004) in those populations examined to date warrants further investigation. For example, it would be extremely useful for ongoing monitoring of the fishery to include sentinel stocks, closed to recreational fishing (i.e. drinking water supply dams such as Mundaring and Serpentine) to help quantify the effects of (legal) fishing mortality on the productivity of these systems. The sentinel stock in the Shannon River (closed to recreational fishing) has recently been included in the annual monitoring program. Therefore, the population biology parameters determined here and management implications may be applicable to other rivers in the fishery, but should be treated with caution. The exceptions would be the Hutt River, due to its relative extreme geographical isolation and translocated population status, and the Harvey Dam, where high growth rates are evident (Morrissey 1975; Lawrence 2007) and the length at first maturity is large.

The high degree of complex habitat in the Warren River (and others throughout much of the remaining marron distribution) mostly consists of large woody debris arising from the intact and relatively pristine riparian vegetation zone and the high bank to surface area ratio; a completely opposite scenario as that which exists in the dams of the region. This complex habitat would facilitate increased survivorship of juveniles by reducing the degree of inter- and intraspecific predation. The increased survivorship of juveniles would result in the high density of adults revealed in the current study (Table 2). This would also be the case in other rivers with similarly largely intact riparian zones, adequate water quality and instream habitat complexity.

The high degree of allochthonous inputs into rivers with intact riparian zones would also provide an increase in organic matter entering the detrital ecosystem that would subsequently become available to marron either as direct consumption of detritus and biofilm, or consumption of higher taxa such as invertebrates and even fish (Beatty 2006). The complex in-stream habitat, inaccessibility of banks, and considerable restrictions on recreational fishing (specifically snare only and ~three week season) in the Warren River have resulted in the relatively low exploitation rate compared with the dam population. Therefore, compared to Wellington Dam, that may have selectivity to slow growing, reproducing animals due to high exploitation, there is limited growth selection pressure from fishing and a greater food resource. This would generally result in great growth rates and productivity of adults in rivers similar to that of dams (this needs further confirmation in other systems; see section on monitoring recommendations below). In addition to complex instream habitat, the translocated Hutt River also experiences warmer average temperatures which would explain why that population had the highest growth rate of the populations studied here.

The marked differences in the growth and mortality rates, production and subsequent levels of fishery exploitation quantified in the current study as a consequence of the contrasting environments in the Warren River and Wellington Dam have implications for the ongoing sustainable management of the dam and river fisheries. The management of the fishery has, in the past shown a preparedness to be adaptable in terms of gear restrictions for dams and rivers. These findings allow the consideration of additional management actions for rivers and dams that would enhance the overall quality of the fishery.

Implications for management

The biomass of legal sized marron is undoubtedly influenced by the rate of recruitment from smaller sized marron and mortality (a function of long-term fishery pressure and natural mortalities). Morrissy (1975) concluded that there is an upper limit to fishing mortality where increased effort is independent of legal sized *C. cainii* catch. Other freshwater crayfish studies have also highlighted the resilience of populations to overexploitation (e.g. *Orconectes virilis* in Momot, 1991). Morrissy (1975) also postulated that the majority of the recreational catch consisted of the faster growing 2+ and 3+ *C. cainii* , since a correlation between growth rate and catchability was found. Following the former hypothesis, Morrissy (1975) concluded that increasing recruitment, not limiting fishing effort, was the most practical method of increasing legal-sized stocks.

The relatively low fishing mortality and exploitation in the Warren River, and probably others within the current distribution (see Chapter 1), suggests that recreational fishing (*F*) has a relatively minor contribution to fully recruited total mortality (*Z*) due to high population abundances (at least in relatively undisturbed river habitats), and a lack of fishing access to the majority of the population stemming from tight fishery regulations that restrict fishing effort. It is likely that the catch decline in the marron fishery has been brought about by increased fishery regulations (Chapter 4). Furthermore, from Chapter 3 it appears that in fact river flow (and dam fullness) influences recreational captures (up to 60% of variation since 1970). However, the reduction in range of marron (documented in Chapter 1) has undoubtedly occurred due to habitat decline, in particular salinisation and eutrophication as has occurred with endemic freshwater fishes of the region (Morgan et al. 2003). This would have resulted in concentrating the current (reduced) fishing effort to within areas that continue to be of adequate water quality; perhaps maintaining the influence of fishing selectivity on these stocks by, in part, off-setting the overall reduction in fishing effort. Despite this concentration of effort, at least in the 'typical' Warren River, fishing mortality appears to contribute to only a minor part of overall mortality of the fully recruited population.

Reservoir populations

Increasing the habitat complexity in reservoirs has the potential to augment the productivity via increasing juvenile survivorship (reducing inter- and intraspecific competition) and providing increased substrate for food resources (e.g. biofilm accumulation) (as shown in Chapters 7 and 8 and by Molony and Bird (2005)). This increase in productivity may translate into a measurable increase in the recruitment to the fishery in dams due to the increased densities and survivorship of the juveniles (see Chapters 7, 8 and Molony and Bird 2005). Although requiring further quantification, these habitats may also reduce the subsequent stunting of the population by providing increased habitat and food resources for adults. It is recommended that:

- Artificial habitats should continue to be placed in these recreationally fished water supply reservoirs during either draining for refurbishment or other low water level periods.
- These habitats should consist of easily obtainable rock walls shown to be most effective at attracting Marron as previously has occurred in Waroona Dam (see Chapter 7).
- The walls should be located at a range of depths, including just below the long term mean waterline to encourage the use by berried females that we have shown to favour shallow habitats (see Chapter 7).
- As catch rates are explained by river flow and dam fullness (see Chapter 3), consultation and cooperation with water management agencies should occur so that the recreational dam fishery is considered in water management decisions.

River populations

The results of the current study suggest that management could sustainably increase the exploitation rates of riverine marron populations (see Chapter 1). However, as overfishing appears to be localised (i.e. marron have relatively high home range fidelity and low dispersal ability) management actions should be designed to spread fishing effort over a greater area because at present it appears to be concentrated in easily accessible sites. For example, during this study it was observed that a high proportion of larger Marron were captured in areas not easily accessible from the banks.

- To facilitate this increased catch and CPUE, the length of the season or bag limits should not be increased *per se* as this may simply result in localised overfishing of easily accessible sites.
- A sustainable increase in total catch and CPUE from rivers could possibly be facilitated by allowing movement and use of legal fishing gear (drop nets) by boat effectively opening up greater areas to fishing.

In addition to temperature regimes influencing growth rates and productivity, it is evident that habitat availability and complexity influences the density, productivity and fishery recruitment of marron in rivers. River flow is positively related to marron catches (see Chapter 3), as a result of increasing habitat and food availability and allowing increased survivorship and growth of juvenile marron; subsequently increasing recruitment to the fishery in subsequent years. An approximate 10% reduction in rainfall has occurred since 1970 in southwestern Australia (IOCI 2002). This has resulted in a ~50% reduction in inflows into water supply dams and it is predicted that this region will continue (see Chapter 3).

- The predicted future reduction in rainfall and river flow and the likely negative impacts on Marron populations needs to be considered when planning for the long-term sustainable management of the fishery.
- More communication and liaison with water managers and extractors should occur to further enable consideration of Recreational Marron Fishery during water management decisions.

It is likely that natural riparian vegetation in rivers would increase the degree of complex habitat by increasing the inputs of large and small woody debris, thus further contributing to Marron productivity by increasing densities and food availability. The importance of intact riparian vegetation along with adequate water quality (particularly with regard to salinity, dissolved oxygen, temperature and groundwater inputs see Beatty et al. 2007) contributed to marron being identified as a keystone species (Nickoll and Horwitz 2000) and appear to be an ideal indicator of river health in this region. Therefore, it is recommended that:

- Programs that protect or rehabilitate river water quality and riparian zones be developed and promoted as a crucial component of the long-term ecological sustainability of the marron fishery.
- The importance of freshwater inputs, both surface and groundwater, for the long-term sustainability of marron populations should be recognised during water management allocation decisions.
- marron should be promoted as a Western Australian faunal icon and used as a key indicator species of river health in southwestern Australia.

Monitoring recommendations

This study has revealed that there are both temporal and spatial variations in growth, mortality and production between populations in the marron fishery and this has implications for the ongoing monitoring of the fishery. There is a need to undertake annual, independent scientific stock assessments of key populations in a number of river and dam stocks; which should include monitoring relative abundances of juveniles and adults over both spatial and temporal scales.

- A better understanding of the impacts of fishing mortality and management regulations could be achieved through monitoring indicator populations; including those that are fished and those sentinel stocks that are not subject to recreational fishing (e.g. Shannon River and large drinking water supply dams such as Mundaring and Serpentine).
- The standardised trapping program employed in the current study appears suitable for assessing systems in terms of length at first maturity, relative abundance of adults, and approximations of densities (see Chapter 7).
- The monitoring program should be used to further refine the juvenile abundance assessment techniques (Chapter 8) and the relative adult abundance monitoring using the trapping technique employed in the current study.

- The independent annual stock assessments should be related to annual recreational catches to validate its predictive power in determining future recruitment to the fishery and subsequent recreational catches.

This program will help ensure that the populations and recreational fishery, remain sustainable in light of predicted environmental change.

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Table 1. Parameters for the seasonal von Bertalanffy growth curves and estimates of mortality of *C. cainii* in the Hutt River (Beatty et al., 2004), Wellington Dam and Warren River, where: $OCL_{\infty mp}$ is the asymptotic orbital carapace length from modal progression, K_{mp} is the curvature parameter from modal progression, t_0 is the theoretical age at which the estimated orbital carapace length is zero, *C* determines the relative amplitude of the seasonal oscillation (where 0 < *C* < 1), t_s determines the phase of seasonal oscillation relative to t_0, R^2 is the coefficient of determination, Z_e is the instantaneous rate of mortality of Marron >legal size, Z_u is the instantaneous rate of mortality of Marron <legal size, F_1 is the instantaneous rates of fishing mortality (determined using Z_e and Z_u) and E_1 is the exploitation rate (i.e. proportion of Z_e contributed by F_1). N.B. All mortality estimates determined by the length converted catch curves used the growth parameters determined from the forced Gulland-Holt plots.

Parameter	Hutt River	Wellington Dam	Warren River
Number of Marron measured	1275	5117	5308
$OCL_{\infty mp}$ *(mm)*	101.9	88.9	74.6
K_{mp}	0.42	0.32	0.23
t_0 *(month)*	1.54	1.36	-2.69
C	0.37	0.69	1.0
t_s	3.85	6.12	2.52
R^2	0.99	0.99	0.99
Months to legal size (80 mm CL) using modal progression	27	42	75
$OCL_{\infty gh}$ *(mm)*		78	105
K_{gh}		0.11	0.14
Months to legal size (80 mm CL) using Gulland-Holt		147	66
Z_u $(1 year^{-1})$	0.41	0.18	0.42
Z_e $(1 year^{-1})$	1.79	0.47	0.59
F $(1 year^{-1})$	1.38	0.29	0.17
E	0.77	0.62	0.29
S_u (% $year^{-1}$)	56	83	66
S_e (% $year^{-1}$)	17	62	55

Table 2. Mark-recapture data from Wellington Dam and the Warren River using opera traps between June 2005 and November 2006. N.B. All estimates for fully recruited (trappable) animals (>~40 mm OCL). Productivity estimates derived only on trappable density estimates from Schnabel multiple mark-recapture and mean annual growth rates derived from mark-recapture and assumes a stable trappable population size (i.e. immigration + recruitment = emigration + mortality).

Mark-recapture information	Wellington Dam females	Wellington Dam males	Wellington Dam TOTAL	Warren River females	Warren River males	Warren River TOTAL
Total number captured	1092	2137	**3229**	1524	2323	**3847**
Number marked	359	680	**1039**	505	667	**1172**
Mean size marked (mm ±1 S.E.)	47.9 (0.26)	50.6 (0.24)	**49.7 (0.19)**	56 (0.51)	55.7 (0.47)	**55.8 (0.35)**
Percentage recaptured (number)	25.1 (90)	41.9 (285)	**36.1 (375)**	36.0 (182)	42.6 (284)	**39.8 (466)**
Mean time at liberty (days)	178 (11)	197 (7)	**193 (6)**	217 (9)	253 (8)	**239 (6)**
Mean size mark-recaptured (mm ±1 S.E.)	50.1(0.47)	52.1 (0.34)	**51.9 (0.29)**	60.9 (0.84)	62.4 (0.70)	**61.9 (0.54)**
Percentage recaptured with ≥1 moult (No.)	46 (41)	47 (135)	**47 (176)**	80 (145)	69 (197)	**73 (342)**
Mean absolute growth rate (mm/yr ±1S.E.)	2.94 (0.53)	2.71 (0.22)	**2.77 (0.21)**	7.68 (0.56)	5.81 (0.37)	**6.54 (0.32)**
Mean relative growth rate ((% OCL /yr ±1S.E.)	6.1 (1.14)	5.3 (0.44)	**5.48 (0.43)**	12.8 (0.93)	9.5 (0.61)	**10.80 (0.52)**
Mean annual weight increase (g)	26.1 (5.0)	26.7 (2.3)	**26.4 (2.1)**	101.3 (8.3)	73.4 (5.1)	**83.9 (4.6)**
Trappable population estimate during study period (Schnabel)	2350	2346	**4292**	2643	4355	**6989**
Density estimate (m^{-2})	0.06	0.06	**0.11**	0.17	0.27	**0.44**
Estimated productivity ($g.m^{-2}.year^{-1}$)	1.63	1.67	**3.02**	17.2	19.8	**36.9**

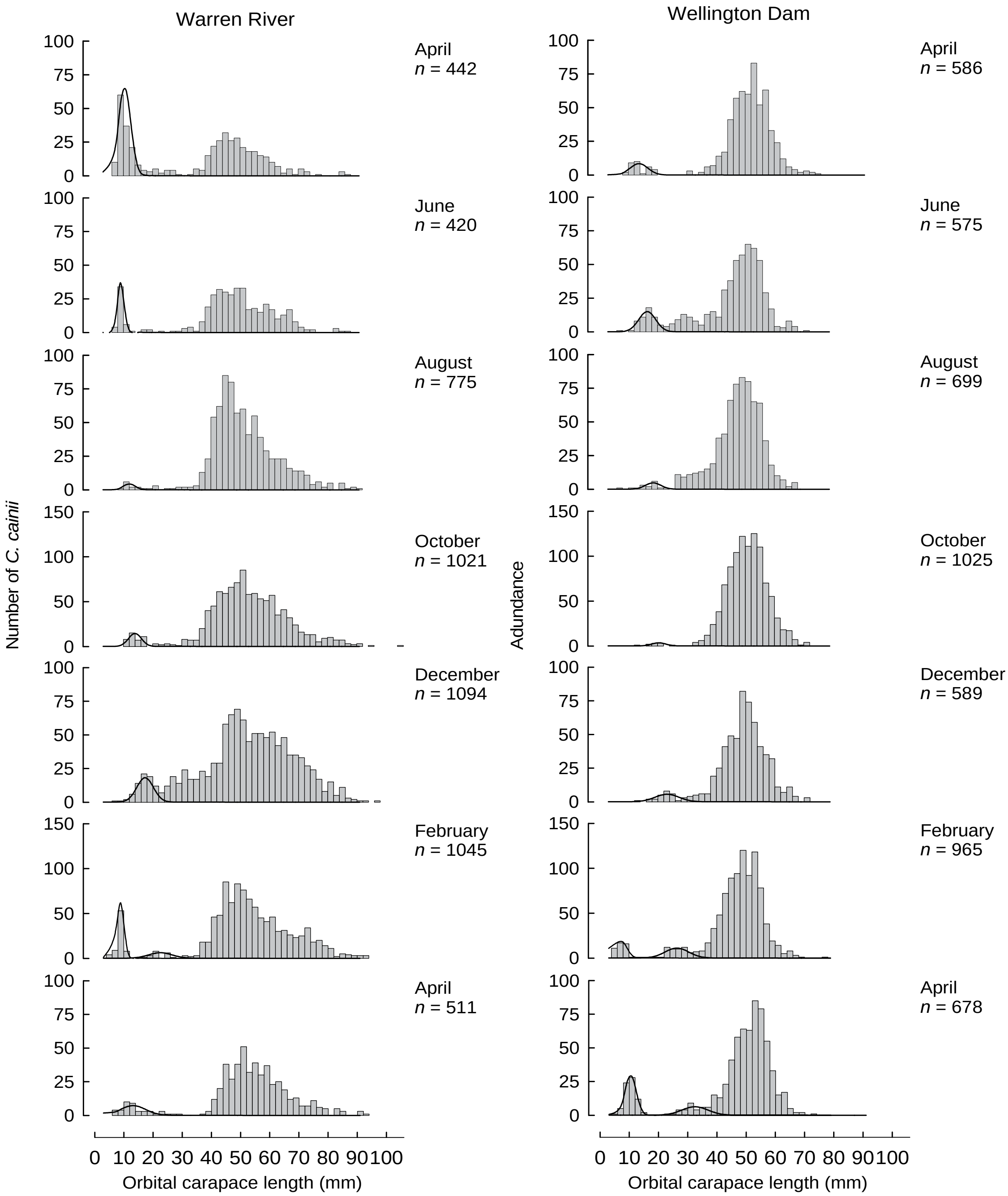


Figure 1. Orbital carapace length-frequency histograms for Marron between April 2005 and April 2006 in the Warren River and Wellington Dam. Normal distributions have been fitted to the one or two size cohorts present in each month that were subsequently used in creating the seasonal von Bertalanffy growth curve. N.B.: *n* = sample size.

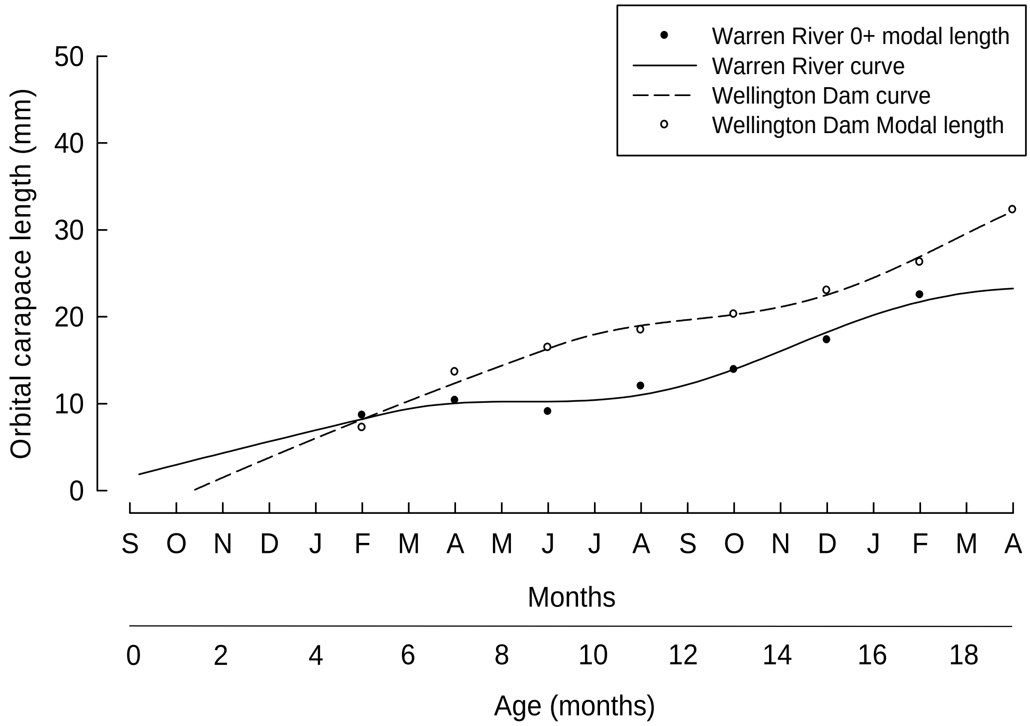
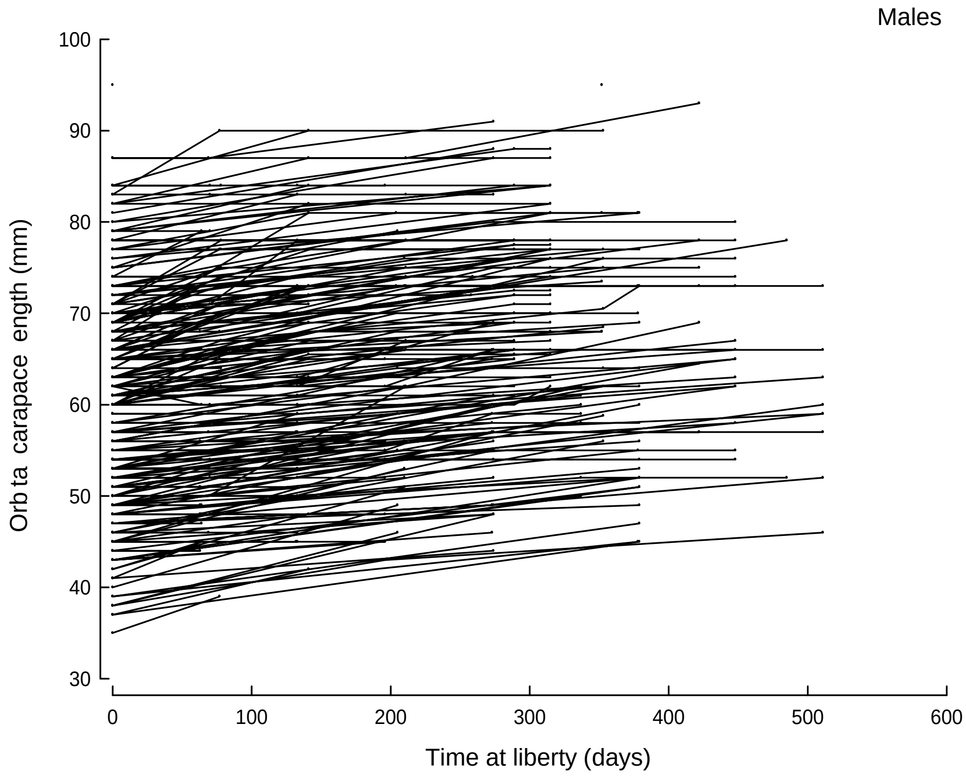


Figure 2. Modified seasonal von Bertalanffy growth curves of Marron in the Warren River and in Wellington Dam. N.B.: Curves were fitted to the monthly mean orbital carapace lengths at age of the 0+ or 1+ cohorts.



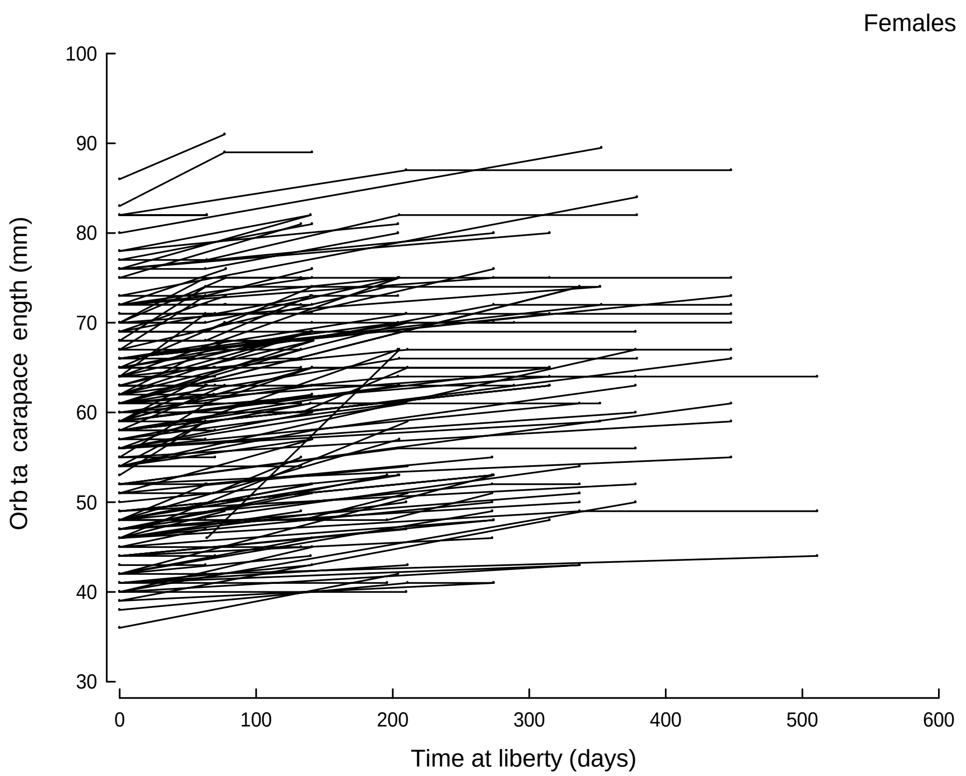


Figure 3. Growth trajectories of male and female Marron from the Warren River as determined by the mark recapture program between June 2005 and November 2006.

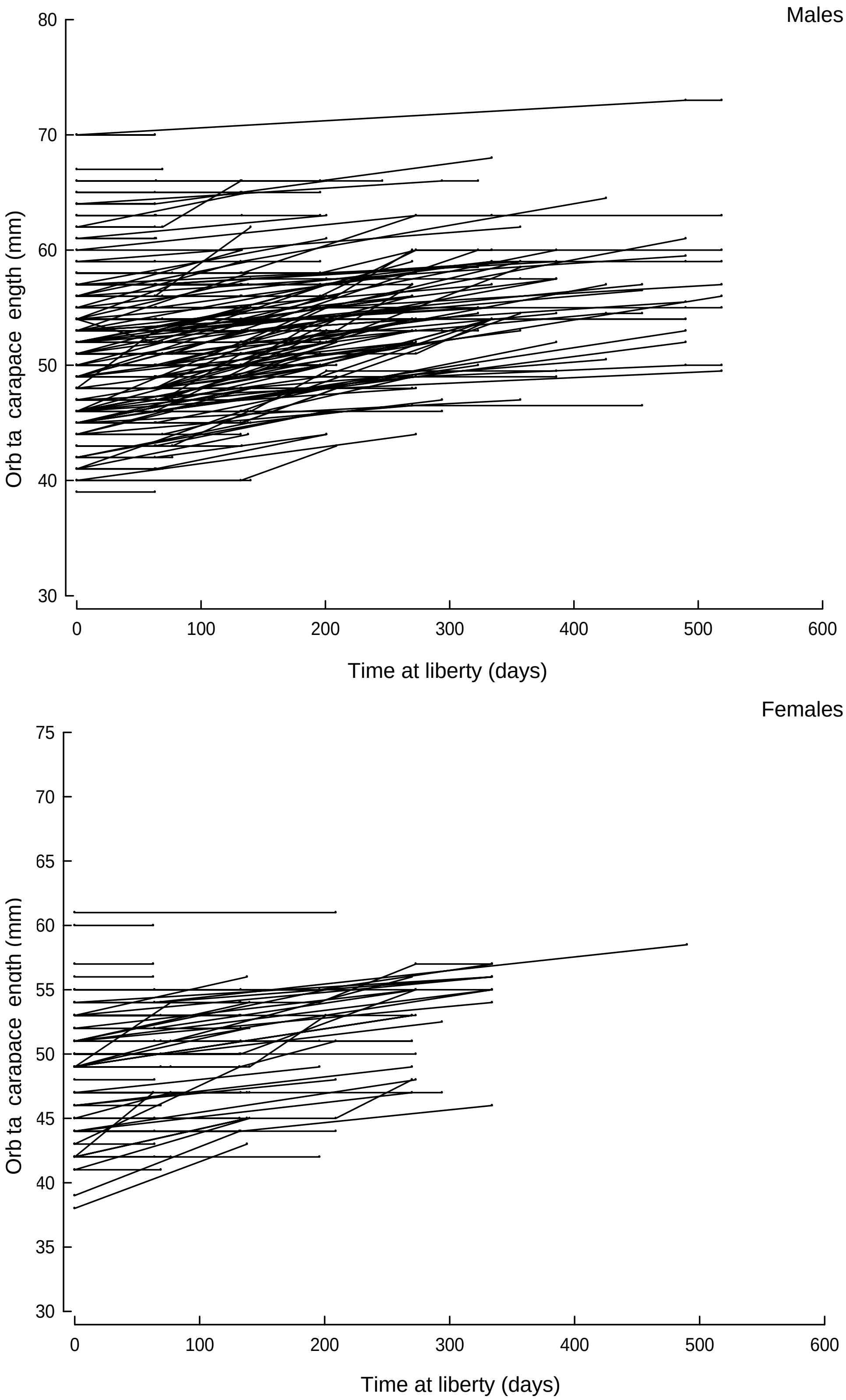
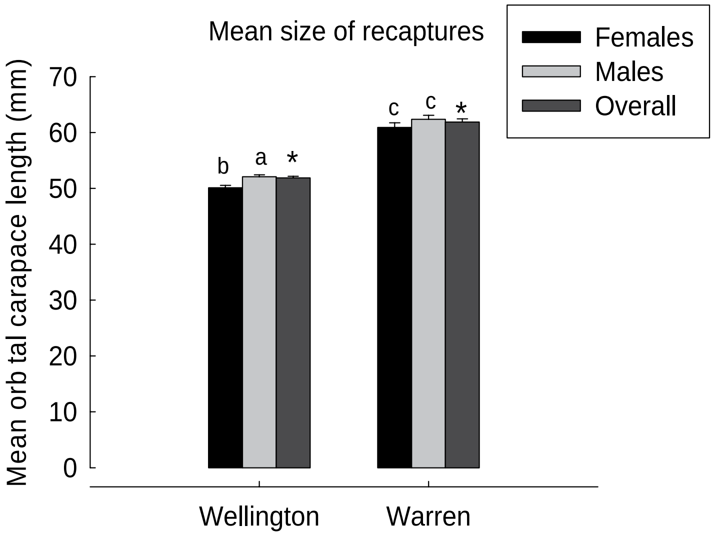
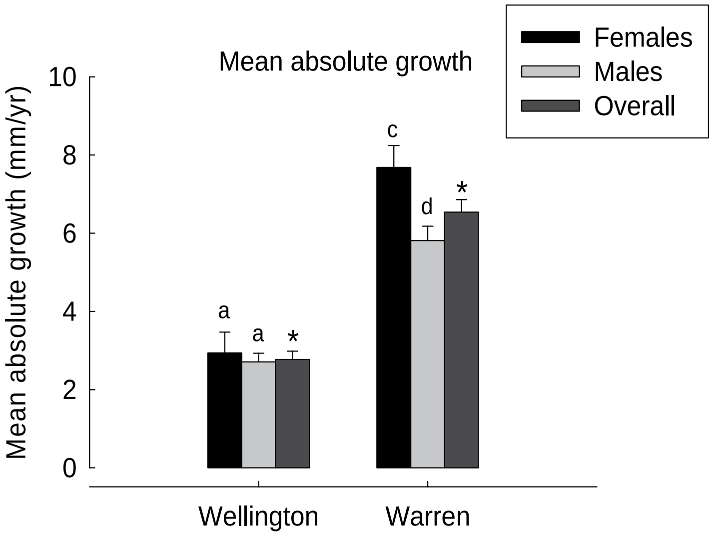


Figure 4. Growth trajectories of male and female Marron from Wellington Dam as determined by the mark recapture program between June 2005 and November 2006.





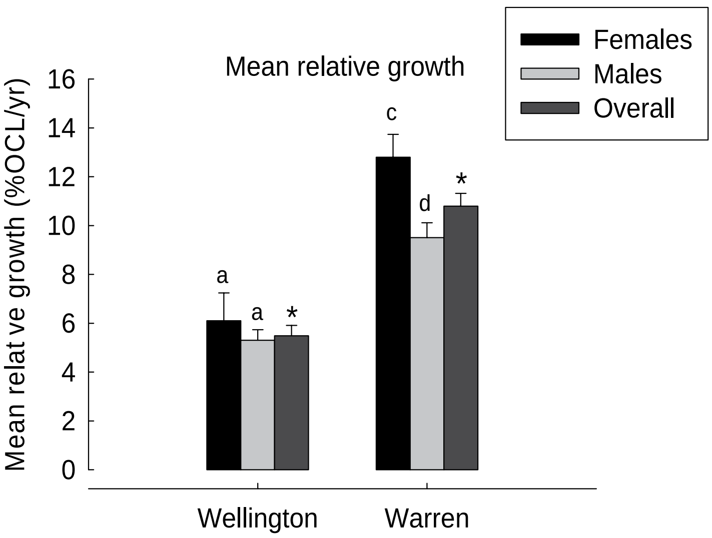


Figure 5. Mean (±1 S.E.) sizes of female and male Marron from the Warren River and in Wellington Dam that were tagged and subsequently recaptured, mean annual absolute growth rate, and mean annual percentage growth (relative to overall OCL). N.B. those categories with different superscripts were significantly different ($p < 0.05$) and * denotes overall differences between rivers ($p < 0.05$).

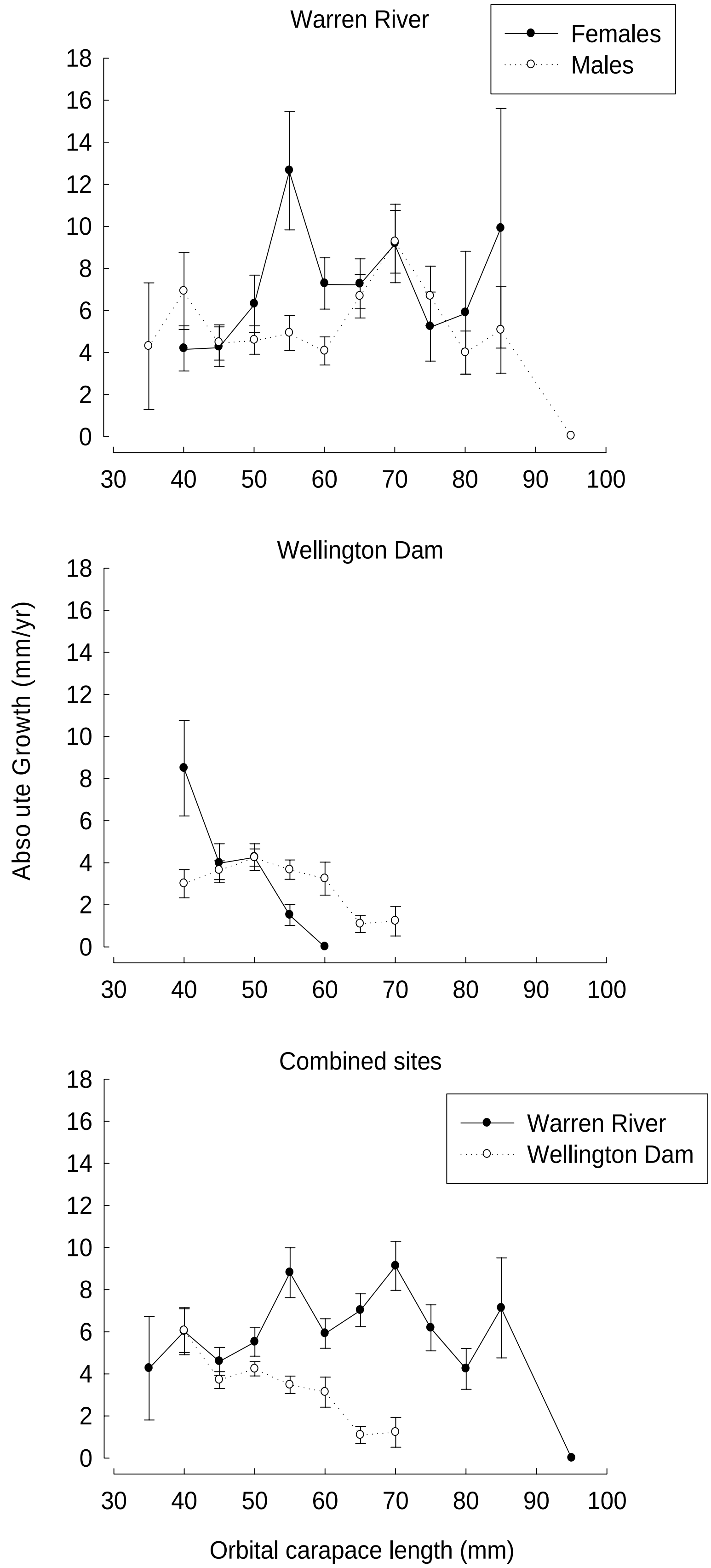


Figure 6. Mean (±1 S.E.) absolute annual growth rates of 5 mm OCL size classes of female and male Marron in the Warren River and Wellington Dam. N.B. bottom graph shows absolute growth rates of pooled sexes at both sites.

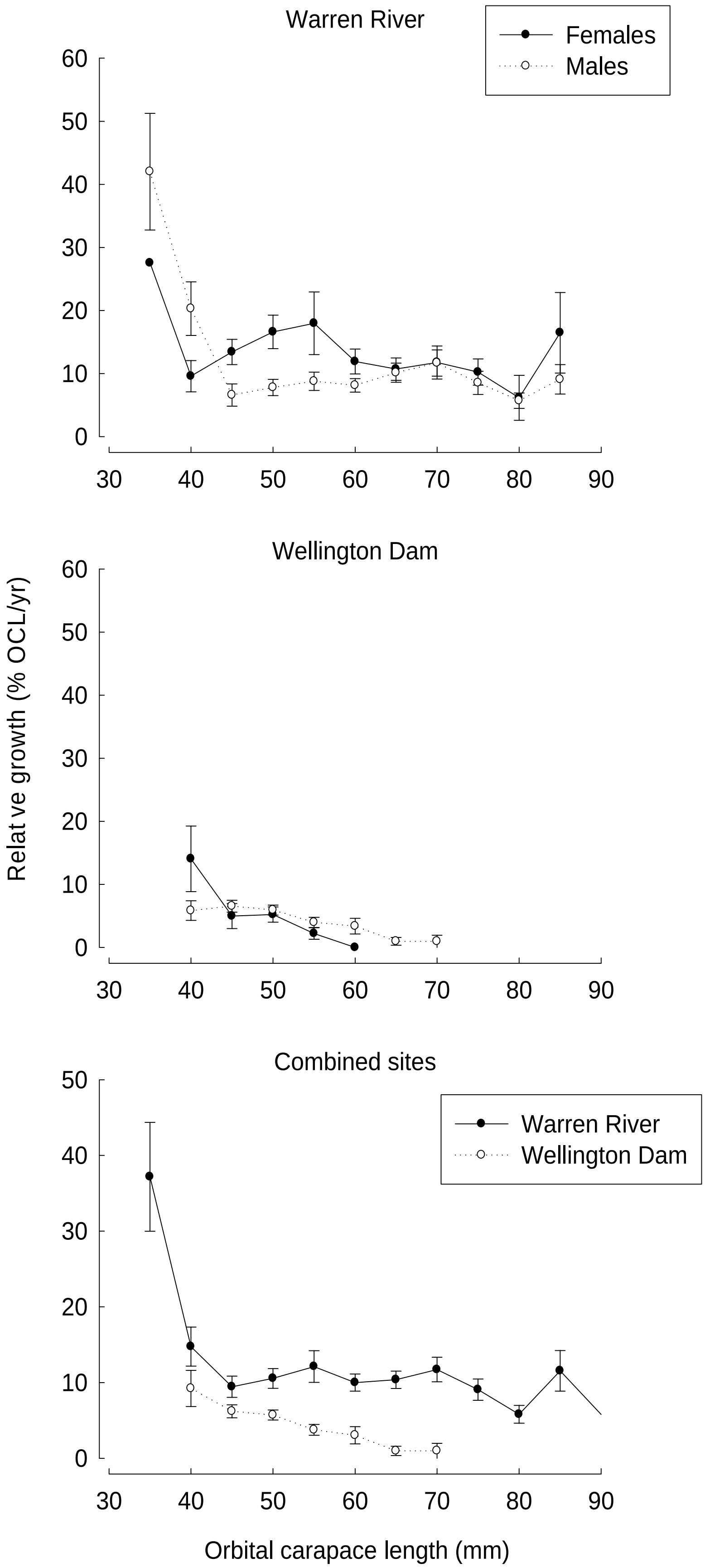


Figure 7. Mean (±1 S.E.) relative annual growth rates (percentage increase of total OCL) of 5 mm OCL size classes of female and male Marron in the Warren River and Wellington Dam. N.B. bottom graph shows relative annual growth rates of pooled sexes at both sites.

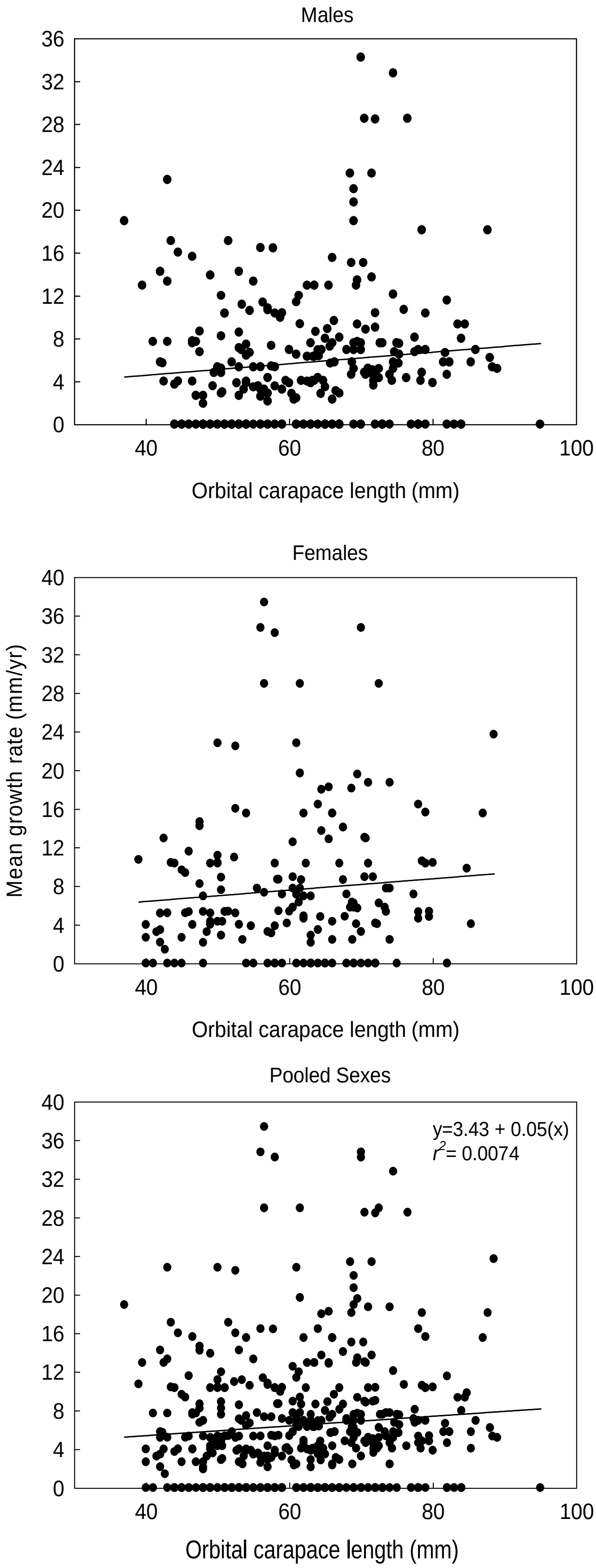


Figure 8. Gulland and Holt plots (i.e. relationship between the mean absolute growth rate and mean size) of male, female, and pooled sexes of Marron in the Warren River.

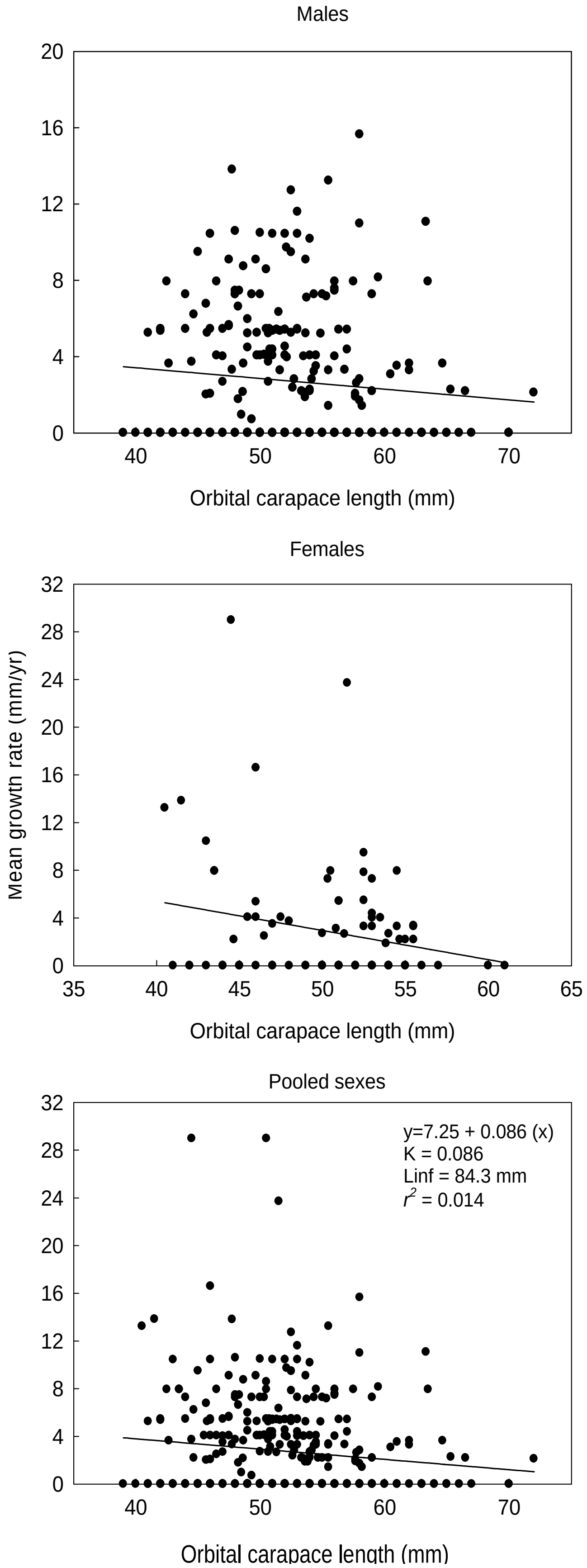


Figure 9. Gulland and Holt plots (i.e. relationship between the mean absolute growth rate and mean size) of male, female, and pooled sexes of Marron in Wellington Dam.

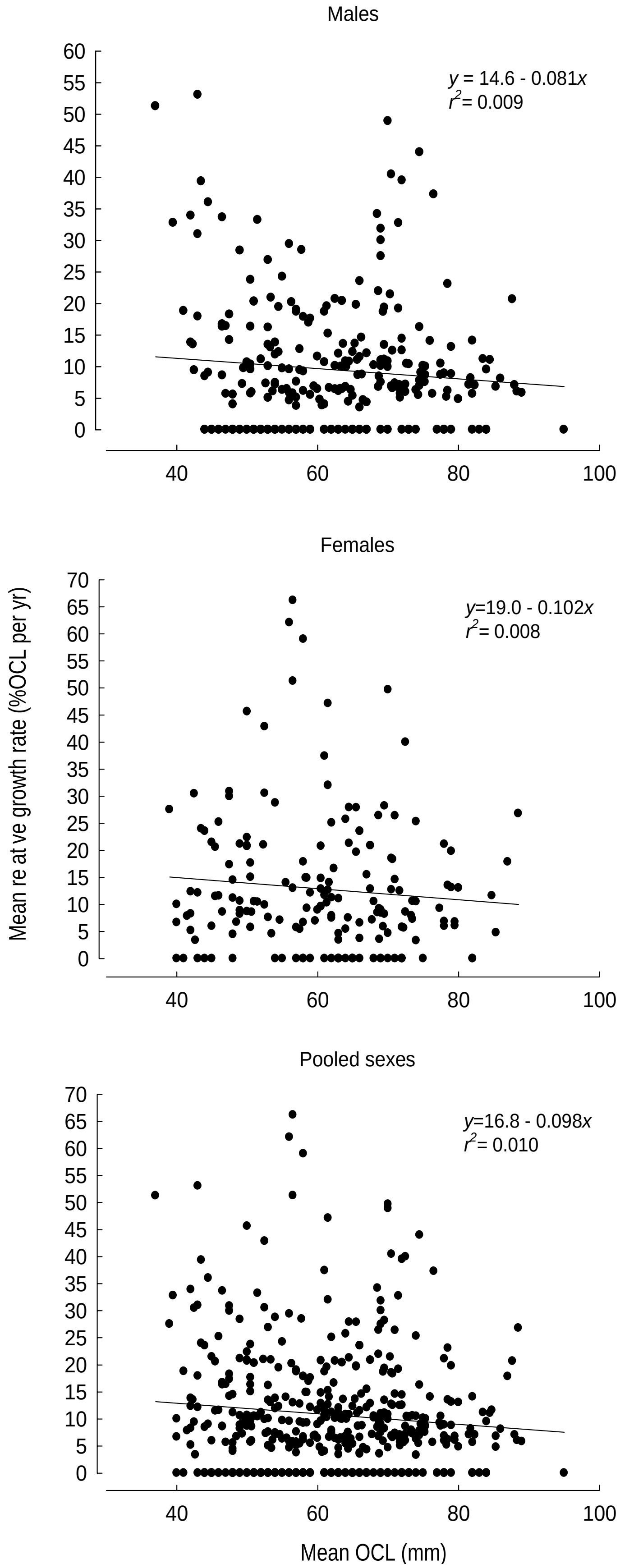


Figure 10. Relationships between the mean annual relative growth rate (% OCL increase per year) and the mean size of male, female and pooled sex Marron in the Warren River.

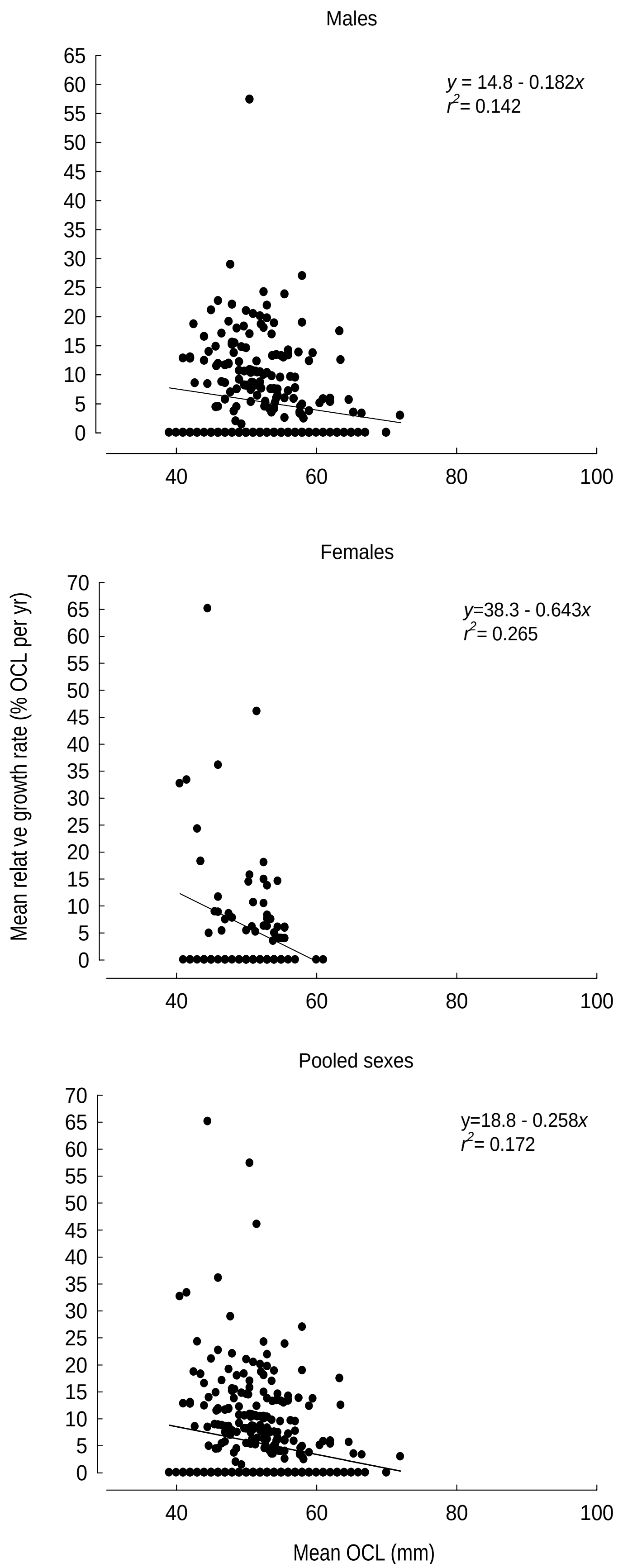


Figure 11. Relationships between the mean annual relative growth rate (% OCL increase per year) and the mean size of male, female and pooled sex Marron in Wellington Dam.

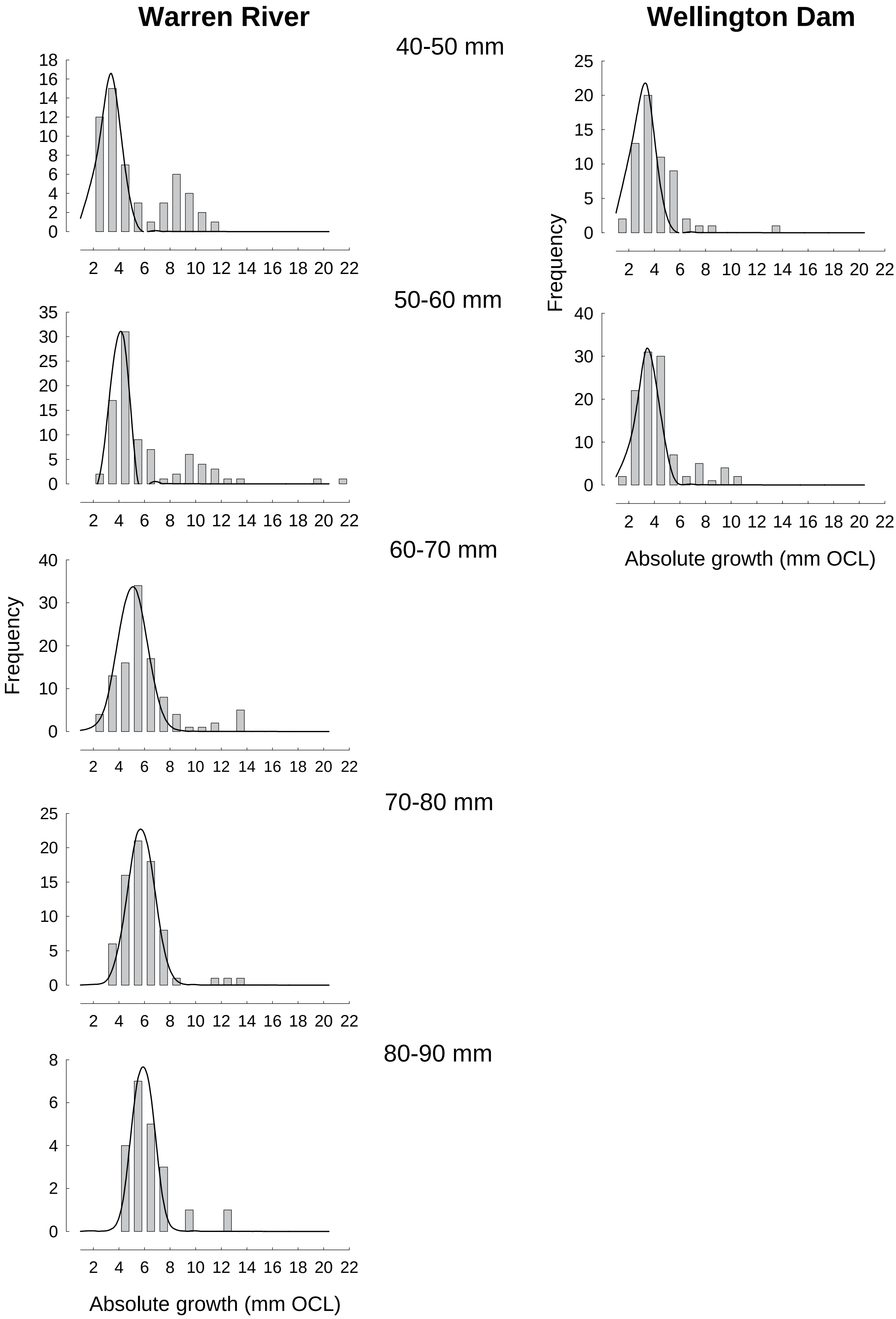


Figure 12. Frequency of the absolute growth increments of various 10 mm OCL size categories of marron that were marked and recaptured in the Warren River and Wellington Dam between June 2005 and November 2006. N.B. Moult increments implied by the sequential modes clearly indicated an increase in the moult increment with size class in the Warren River; and those individuals that did not grow were excluded.

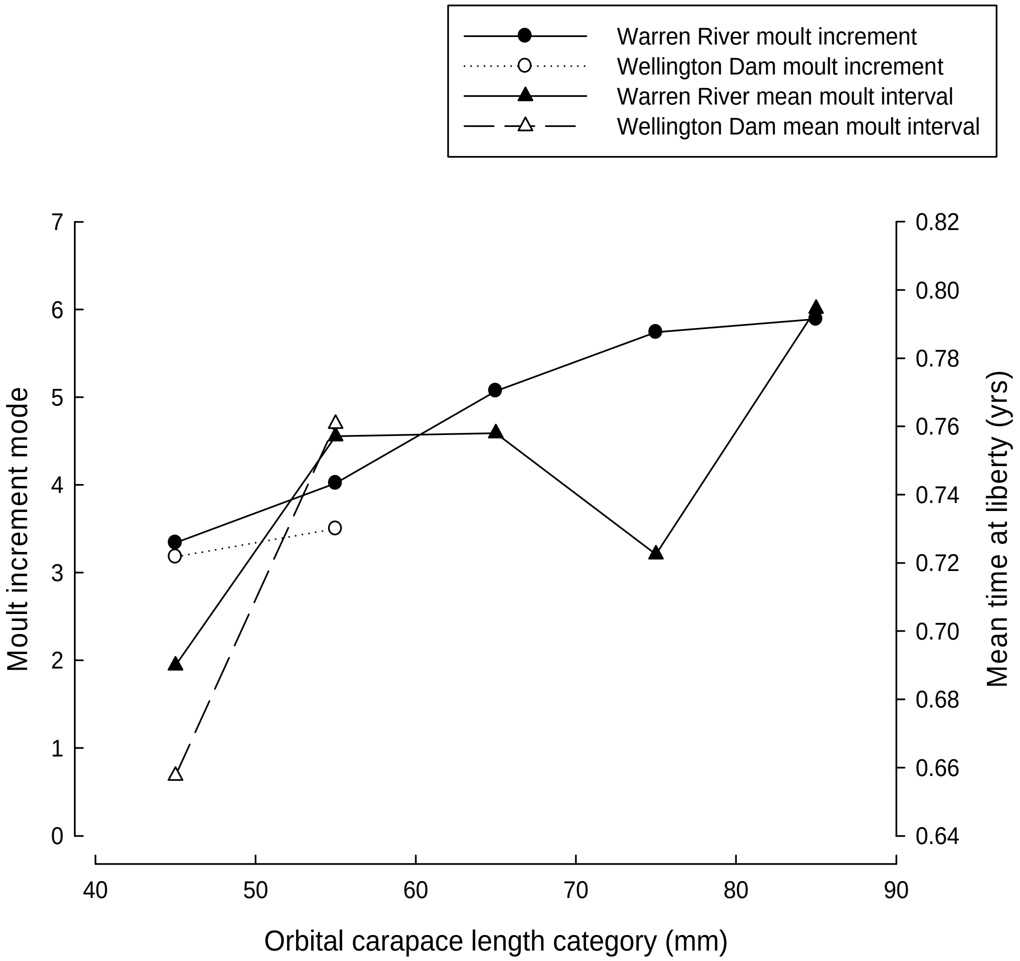


Figure 13. Moult increments for size categories (10 mm OCL) of Marron in the Warren River and Wellington Dam, as implied by sequential modes of the frequency of absolute growth increments, and the mean time at liberty of Marron that moulted once in each system.

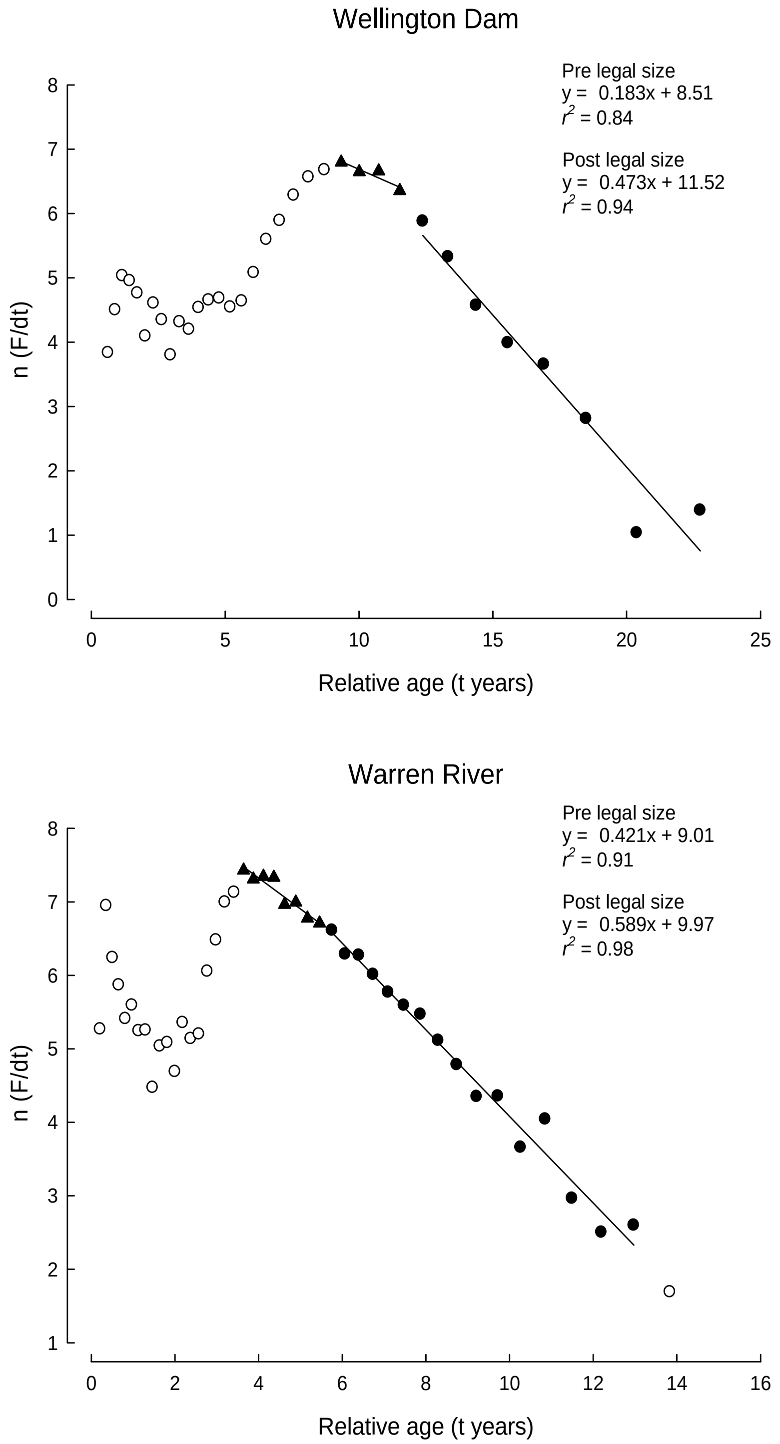


Figure 14. Length-converted catch curve of Marron in the Warren River and Wellington Dam. N.B.: Slope of the regression line represents the instantaneous mortality rate of the exploited population ($\underline{Z}_e$). Data points represented by triangles were excluded from regression as they were size classes not subjected to legal fishing and those with open circles were excluded as they represent mean ages that were not fully recruited (ascending data points) or those with small sample sizes (<10 individuals).

6.0 Spatial and temporal variation in reproductive characteristics of marron, *Cherax cainii* (Crustacea: Decapoda), in southwestern Australia

Martin de Graaf, Vinh Nguyen and Stephen Beatty

6.1 Introduction

Intraspecific plasticity in reproductive characteristics like fecundity and size-at-maturity is common in freshwater crayfish and is influenced by both extrinsic factors like different environmental conditions and intrinsic factors such as population genetics and density (Honan and Mitchell 1995, Austin 1998, Reynolds 2002 and references therein, Jones and Coulson 2006).

In comparison with the amount of research into marron aquaculture (Lawrence and Jones 2002 and references therein) and despite the vulnerability of marron and its recreational fishery, limited research has been conducted into the reproductive biology of *C. cainii* in the wild. The available studies, however, clearly demonstrated the potential for considerable intra-specific plasticity in the reproductive biology of *C. cainii*. Morrissy (1970) and Beatty et al. (2003a) found that average sexual maturity of female *C. cainii* was ~35 mm orbital carapace length (OCL) in the Warren River and Waroona Dam. While Beatty et al. (2004) showed that average female size-at-maturity in the Hutt River was ~70 mm OCL, which was significantly larger that the legal minimum size at that time.

As a result, the Department of Fisheries decided after consulting with the appropriate stakeholders, to manage the Hutt River as 'trophy water' with an increased minimum legal size and a reduced daily bag limit from 2007 onwards. This example of plasticity in female marron size-at-maturity and its direct implications for the management of the Recreational Marron Fishery (RMF), proves the urgent need for a comprehensive study of reproductive characteristics of *C. cainii* throughout the southwest of Western Australia.

The aim of this Chapter was to investigate temporal and spatial variation in reproductive characteristics (size-at-maturity, ovarian fecundity, pleopodal fecundity) of *C. cainii* in the southwest of Western Australia. Patterns in reproductive biology are discussed with regards to their implications for the sustainable management of the popular Recreational Marron Fishery.

6.2 Materials and Methods

Study sites and sampling

Marron were collected using traps, drop nets and scoop nets in rivers and dams throughout the southwest of Western Australia in 2005 and 2006 (Fig. 1). Size (mm orbital-carapace length (OCL); distance between the post-orbital margin and the lateral posterior edge of the carapace) and the presence of eggs or juveniles was recorded for each female captured. Female marrons were immediately euthanized in ice slurry for transport to the laboratory to be used for internal macroscopic examination of gonads.

Clutch size estimates

A method was trialled in October 2005 to rapidly obtain a relative estimate of pleopodal fecundity, without manually counting the eggs. The relative fullness of a clutch of eggs attached to the female's pleopods (Fig. 2) was visually estimated from 0-100% based on our experience of viewing egg masses on females carrying full broods of eggs. Females were collected using traditional management sampling protocols, (i.e. baited drop nets in the Warren River and scoop netting around baits in Wellington Dam).

Size-at-maturity

The gonads of female marron were macroscopically assigned to developmental stages following Beatty et al. (2003). Maturity in female marron was assumed to have been attained in animals that had either, gonads in mature stages of development (stages III-VI), or were ovigerous (Stage VII). Size-at-maturity data of *C. caini* in the Hutt River (2001 data, Beatty et al. 2004), Waroona Dam (1999-2000 data, Beatty et al. 2003a) and Wellington Dam (1978 data, Morrissy unpublished data) were re-analysed for consistency of methodology.
Spatial and temporal differences in size at which 50% of female marron are mature ($OCL_{50\%}$) was analysed by a nonlinear regression routine using the statistical package SPSS 11.5.0™. The equation used was:

$$P_i = 1/[1+e^{-\ln 19(OCL_i - OCL_{50})/(OCL_{95} - OCL_{50})}]$$

Where P_i is the proportion mature marron at OCL_i and OCL_{50} and OCL_{95} are the OCLs at which 50% and 95% of the assemblage is mature, respectively. Females used to develop this relationship were those caught between May and October 2005 and/or 2006 (i.e. immediately prior to and during, the breeding period) (Beatty et al. 2003, 2004).

Fecundity

Ovarian (or potential) fecundity was determined in females immediately prior to spawning via manual counts of oocytes in mature ovaries (≥ stage IV, Beatty et al. 2003a). Ovaries were removed from euthanized marron and stored in 95% ethanol.

To determine pleopodal (or effective) fecundity, berried females were collected using baited traps in rivers and dams in September and October 2006. Immediately upon capture, females were measured to the nearest 1 mm (OCL) and four alternate pleopods with eggs were removed, stored in 100% ethanol and manually counted. Historical fecundity data of female *C. cainii* in Waroona Dam (1999-2000 data, Beatty et al. 2003a) and Warren River (1968 data, Morrissy 1970) were re-analysed to investigate temporal variation. Spatial and temporal variation in ovarian and pleopodal fecundity data were analysed using ANCOVAs with size (mm OCL) as a co-variate. Harvey Dam and Moore River (all individuals >55 mm OCL) were excluded from the ovarian fecundity analysis due to the limited range of data available for each site. Harvey Dam (all individuals >55mmOCL) and Shannon River (all individuals <40mm OCL) were excluded from the pleopodal fecundity analysis due to the limited range of data available for each site.

6.3 Results

Clutch size estimates

The results of visual estimates of the volume of the clutch of eggs carried by ovigerous females of different sizes in Wellington Dam and Warren River are shown in Fig. 3. Two patterns were observed in the visual estimates of batch size; the volume of the egg masses of ovigerous females in Wellington Dam appeared lower than in Warren River, and the volume of the egg masses of ovigerous females appeared to decrease sharply with size in both systems.

Size-at-maturity

No temporal variation was observed in female size-at-maturity, either in Waroona Dam between 1999 and 2006 or in Wellington Dam between 1978 and 2006 (Table 1). However, size-at-maturity was highly variable among the sampled water bodies; ranging from ~31 mm OCL (Waroona Dam 2006) to ~67 mm OCL (Hutt River 2001) (Fig. 4, Table 1). Female marron in the Hutt River, Moore River and Harvey Dam reach maturity at larger sizes as shown by their large size at first maturity (>50 mm OCL) and large $OCL_{50\%}$ (~60 mm OCL). On the other hand females in Waroona Dam, Drakesbrook Dam, Wellington Dam, Collie River, Preston River and Murray River reached first maturity at just ~30 mm OCL and $OCL_{50\%}$ ranged between 30-40 mm OCL. In the Margaret River and Blackwood River female marron reached first maturity at small sizes (~30 mm OCL) but $OCL_{50\%}$ was large at ~60 mm OCL and similar to $OCL_{50\%}$ observed in the Hutt River, Moore River and Harvey Dam. Despite the large sample size, size-at-maturity patterns based on macroscopic analysis of gonads prior to the breeding season are the least clear in the Warren River and appear to fluctuate.

Fecundity

No temporal differences in mean ovarian fecundity were observed in the Warren River between 1968 and 2006 (ANCOVA, $F_{1,66}$=0.0069, P=0.79) and Waroona Dam between 1999 and 2006 (ANCOVA, $F_{1, 35}$=0.57889, P=0.45) (Fig. 5). In 2006, mean pleopodal fecundity in the Warren River was significantly higher than in 1968 (ANCOVA, $F_{1,65}$=6.75, P=0.012). No temporal difference in mean pleopodal fecundity was observed in Waroona Dam between 1999 and 2006 (ANCOVA, $F_{1, 35}$=0.82830, P=0.37).

An overall significant spatial effect was observed in ovarian fecundity (ANCOVA, $F_{10,174}$=9.0134, P<0.0001) between the 11 sampled locations (Fig. 6a). Among the sampled locations ovarian fecundity appeared to be higher than average in the Preston River, Drakesbrook Dam and Waroona Dam and lower than average in the Denmark River. However, no significant spatial variation (Fig. 6b) was observed in pleopodal fecundity (Warren River, Murray River, Preston River, Blackwood River, Wellington Dam and Waroona Dam, ANCOVA $F_{5,105}$=2.23, P=0.057).

Mean pleopodal fecundity (all sites pooled) was significantly smaller (~40%) than mean ovarian fecundity (all sites pooled) (Fig. 7, ANCOVA: $F_{1, 341}$=369.59, P<0.0001).

6.4 Discussion

Clutch size estimates

Differences in the results for the visually estimated volumes of clutch size carried by ovigerous females between the Warren River and Wellington Dam could be the result of different environmental conditions in the two systems. However, no significant differences were observed between Warren River and Wellington Dam either in ovarian fecundity ($F_{1,26}$=0.23, P=0.63), or pleopodal fecundity ($F_{1,51}$=0.86, P=0.36) as determined by manually counting eggs (see also Fig. 6). Morrissy (1970) mentioned that handling of berried females results in the loss of eggs. The most striking difference between the Warren River and Wellington Dam has been the method of capture and especially the large difference in handling time. In the Warren River berried females were captured using traditional drop nets. Females were collected and measured within 30-60 minutes. However, in Wellington Dam females were collected using traditional scoop nets and were left in buckets for more than 4 hours before being measured and large numbers of dislodged eggs were found at the bottom of the buckets. The substantial difference in handling time is the most likely explanation for the lower visual estimates of clutch size in Wellington Dam. The female marron used to determine ovarian and pleopodal fecundity in both systems by manually counting the eggs were collected using the same method (traps) and handling time.

A reduction in relative fecundity (number of eggs per gram body weight) with age/size, (i.e. reproductive senescence) is not uncommon among crustaceans (Bertelsen and Matthews 2001, Goñi et al. 2003). Relative pleopodal fecundity decreased slightly with size (Fig. 8), however, the reduction is modest and the relationship is weak (R^2=0.23). One explanation for the unexpected sharp decrease in visually estimated clutch volume with size (Fig. 3) might be due to a bias in the visual assessment. For example, a maximum clutch of small eggs on a small female might simply look 'larger' and will be given a high percentage score while a maximum clutch of small eggs on a large female might appear less impressive and will unconsciously be given a lower percentage score. Another explanation might be that larger females have a more powerful flick of the tail, hence losing more eggs compared to small females when stored in buckets before measuring and losing more eggs over time (handling time- Warren River short, Wellington Dam long).

Visually estimating clutch size volume of ovigerous females appeared to be a highly subjective and inaccurate method to determine spatial/temporal differences in pleopodal fecundity. In sharp contrast with visually estimating clutch size, manually counting the eggs of four alternate pleopods is an objective, robust, simple and quick method that generates high quality pleopodal fecundity data. Further attempts to develop the method for 'estimating clutch volume' were abandoned after the poor results in 2005. Furthermore, these results clearly demonstrated the need to review the Department of Fisheries traditional (drop nets in rivers, scoop nets in dams) methodologies and emphasized the need for standardised methods of capture (e.g. baited traps) that reduce handling time and subsequent egg dislodgement.

Fecundity

The number of eggs a female crayfish of a given size carries has been known to vary temporally and/or spatially in response to environmental conditions (Reynolds 2002 and references therein). In marron the relationship between size and ovarian or pleopodal fecundity appeared to be a conservative reproductive characteristic with little spatial or temporal variation. The temporal variation in pleopodal fecundity in the Warren River between 1968 and 2005 is most likely due to a difference in capture technique and handling time of berried females after capture.

Marron ovarian fecundity differed from pleopodal fecundity by almost 40%, this is high but within the range (20-40%) reported for other crayfish species (Reynolds 2002 and references therein). Egg loss during spawning appeared to be independent of female size, (i.e. during spawning small and large female marron lose the same number of eggs ~40%).

Size-at-maturity

Phenotypic plasticity in size/age at maturity is suggested to be a unique adaptive mechanism to withstand high mortality rates under adverse biotic or abiotic conditions such as predation, desiccation or fishing pressure. For example, phenotypic plasticity in maturation size is remarkably high in the freshwater fish Nile Tilapia (*O. niloticus)*, ranging from 39 cm TL (Lake Turkana, Kenya, Lowe-McConnell 1958) to 9 cm SL with an age of just six months (Korokara resevoir, Cote d'Ivoire, Duponchelle and Panfili 1998). Similar patterns have also been observed among crustaceans; reduction in male and female size at maturity with increasing temperature in western rock lobster *Panulirus cygnus* (Melville-Smith and de Lestang 2006); reduced female size at maturity with increasing temperature in *Homarus americanus* (Little and Watson 2005); decreased female size at maturity with increasing temperature and/or high exploitation rates in *Homarus americanus* (Landers et al. 2001); reduced male size at maturity in environments with high population density, limited food or fluctuating water temperature or quality in the freshwater crayfish *Procambarus clarkia* (Huner and Romaire 1978).

Although sample size and/or size range of samples may not be sufficient at this point for several of the studied water bodies, our attempt to provide an overview of variation in female size at maturity has generated several interesting trends.

In the Hutt River minimum legal size and bag limit was adjusted in the 2007 marron season by the Department of Fisheries after Beatty et al. (2004) clearly showed that average female size-at-maturity (~70mm OCL) was significantly larger than the legal minimum size at that time (55mm CL before 2007) in this translocated population. Interestingly, in contrast to American lobster (Little and Watson 2005) and western rock lobster (Melville-Smith and de Lestang, 2006), marron appear to increase in size at maturity with increasing temperature, which may be related to increased growth rates (Beatty et al. 2004). Preliminary results indicated that female $OCL_{50\%}$ in the Blackwood River, Margaret River and Moore River was 64, 58 and 57 mm OCL respectively. These $OCL_{50\%}$ sizes are equal to, or larger, then the present minimum legal size (57.5 mm OCL). Given that a similar discrepancy between $OCL_{50\%}$ and the minimum legal size was the basis for revising the minimum legal size in the Hutt River, a similar revision of the legal minimum size may need to be considered in the Blackwood, Margaret and Moore River.

In 2002, Waroona Dam, the third most popular dam in the Recreational Marron Fishery (~15-20% of dam effort) was completely drained by the Water Corporation for refurbishments of the dam wall. In 2003 and 2004, Waroona Dam was restocked with ~50,000 newly bred juveniles from the Pemberton Fisheries Research Centre and ~1200 broodstock removed from the dam in 2002 before the complete drainage (Beatty et al. 2003 & Molony et al. 2005). Waroona Dam was closed during the 2002-2005 marron seasons to allow the marron stocks to rebuild. Waroona Dam was opened again in the 2006 Recreational Marron Fishery season (two weeks in January) but is now managed as a ‘Trophy Water’ with an increased minimum legal size (90mm CL ≈ 65mm OCL) and a reduced daily bag limit of five marron. This major event appeared to have had no significant effect on female size at maturity and fecundity (Table 1, Fig. 5b).

No temporal differences in size at maturity were observed in Wellington Dam between 1978 and 2005 (Table 1). The marron population in Wellington Dam is likely to be stunted, as indicated by reduced growth (see Chapter 5) and only a very small proportion of the population is larger than minimum legal size (de Graaf, unpublished data) similar as reported for *Astacus astacus* populations in Finland (Huner and Lindqvist 1986).

Furthermore, in Wellington Dam $OCL_{50\%}$ determined by dissection and macroscopic analysis of the gonads of females prior to the breeding season was smaller than the $OCL_{50\%}$ calculated from berried/non-berried ratios during the breeding season (Table 1). A discrepancy between the smallest size considered mature by dissection and the smallest ovigerous female found in the same location was also observed in American lobster (Little and Watson 2005) and may suggest a delay between physiological and functional maturity. Hence small mature females as determined by dissection may form no part of the actual reproductive population and $OCL_{50\%}$ as determined by dissection might be an underestimation of size at maturity.

Although dissection and macroscopic analysis of the gonads may underestimate size at maturity, the use of berried/non-berried ratios to determine size-at-maturity is even more likely to overestimate size at maturity. Firstly, ovigerous females might be underrepresented in samples due to trap shyness or egg loss (Honan and Mitchel 1995 and references therein). Secondly, in species like marron with a very short peak breeding period (a few weeks; Beatty et al. 2003a) that is likely to vary spatially and temporally, timing of sampling is crucial. Sampling too early or too late in the season will result in 'false negatives' (i.e. females with mature eggs that are not berried yet, or females that berried up early in the season will have already dropped their juveniles). Therefore, size at maturity using berried/non-berried ratio's are highly likely to overestimate size at maturity.

Female freshwater crayfish are known to grow and reproduce in alternate years (Huner and Lindqvist 1986, Hamr and Richardson 1994, Hamr 1996) resulting in less than 100% of mature females being berried or having mature gonads. If this occurs, estimating size at maturity using berried/non-berried ratios or dissection will fail as mature but non-reproductive females will be recorded as immature, resulting in a overestimation of size at maturity. Alternating growth and reproduction and the presence of mature non-reproductive females in samples may be the most likely explanation for the unexpected patterns of a decrease in percentage females with mature gonads with increasing size in the Warren River and Shannon River (Fig. 4).

A trade-off in resource allocation between growth and reproduction might be caused by cooler climatic conditions and nutrient poor environments which enable female crayfish to acquire enough energy for both growth and reproduction (e.g. *Parastacoides tasmanicus*; Hamr and Richardson 1994.) This might explain the low percentage of reproductive females in the Shannon River. During the 2006 breeding season the water temperature in the Shannon River (~15ºC) was three to four ºC cooler than seven other southwestern rivers and dams (see Chapter 7). The unexpected reduction in the proportion of reproductive females between 40 to 70 mm OCL in Warren River was also recorded in 1968 (Morrissy 1970). In 2006 marron densities were higher in the Warren River than four other rivers (see Chapter 7) and the presence of mature non-reproductive females might also be density dependent (Jones and Coulson 2006).

A better methodology to determine size-at-maturity, (i.e. a method that incorporates mature but non-reproductive females), needs to be developed for marron. Several secondary sexual characteristics may have the potential to be used to distinguish between immature, mature reproductive and mature non-reproductive females. The presence of plumose setae on the pleopods is an unreliable indicator of the reproductive condition of female marron (Morrissy 1970). Honan and Mitchel (1995) showed clear difference in abdominal width between males, immature females and mature females. Broadening of the female abdomen at maturity is common in crayfish. This method has been successfully used in American lobster research (Landers et al. 2001, Little and Watson 2005) and may be a useful method to determine female reproductive condition in marron but not functional maturity. Another promising method to determine female reproductive condition is female gonopore development. Honan and Mitchell (1995) and Hamr (1996) successfully used gonopore development stages to distinguish between immature, mature non-reproductive and mature reproductive females in the Australian freshwater crayfish *Euastacus bispinosus* and *Astacopsis gouldi*, respectively.

This project clearly demonstrated the need for consistent sampling techniques to be used in both dams and rivers when studying marron reproductive biology. It is of utmost importance that surveying marron populations in rivers and dams to determine size-at-maturity is continued in order to determine which other water bodies might need to be managed as 'Trophy waters' (i.e.

an increased minimum size and reduced bag limit). Furthermore, future research should focus on developing a technique to determine size-at-maturity using secondary sexual characteristics.

6.5 References

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Table 1. Minimum size at first maturity and $OCL_{50\%}$ for female *C. cainii* in river and dams throughout the southwest of Western Australia. Data for the Hutt River in 2001 and Waroona Dam in 1999 are from Beatty et al. (2005) and Beatty et al. (2003), respectively.

Location	Year	Minimum Size at First Maturity (mm OCL)	$OCL_{50\%}$ (mm)	CI
Hutt River	2001	53	66.8	65.5-68.6
Moore River	2006	58	56.6	
Murray River	2006	28	34.6	31.5-37.7
Harvey River				
Waroona Dam	2006	34	30.4	19.5-41.3
Waroona Dam	1999	30	34.5	31.2-37.9
Drakesbrook Dam	2006	37	22.6	
Harvey Dam	2005	54	57.9	54.7-61.1
Collie River	2006	30	30.8	18.4-43.2
Wellington Dam	2005	32	38.6	37.3-40.0
Wellington Dam*	2005		43.9	42.1-45.6
Wellington Dam*	1978		43.7	42.2-45.2
Preston River	2006	33	43.3	35.0-51.6
Margaret River	2005/2006	27	58.0	54.4-61.6
Blackwood River	2005/2006	33	63.7	57.2-70.3
Warren River	2005/2006	32	36.7	
Shannon River	2006	31		

* ratios of berried/non-berried during the breeding season used instead of macroscopic analysis of gonads prior to the breeding season

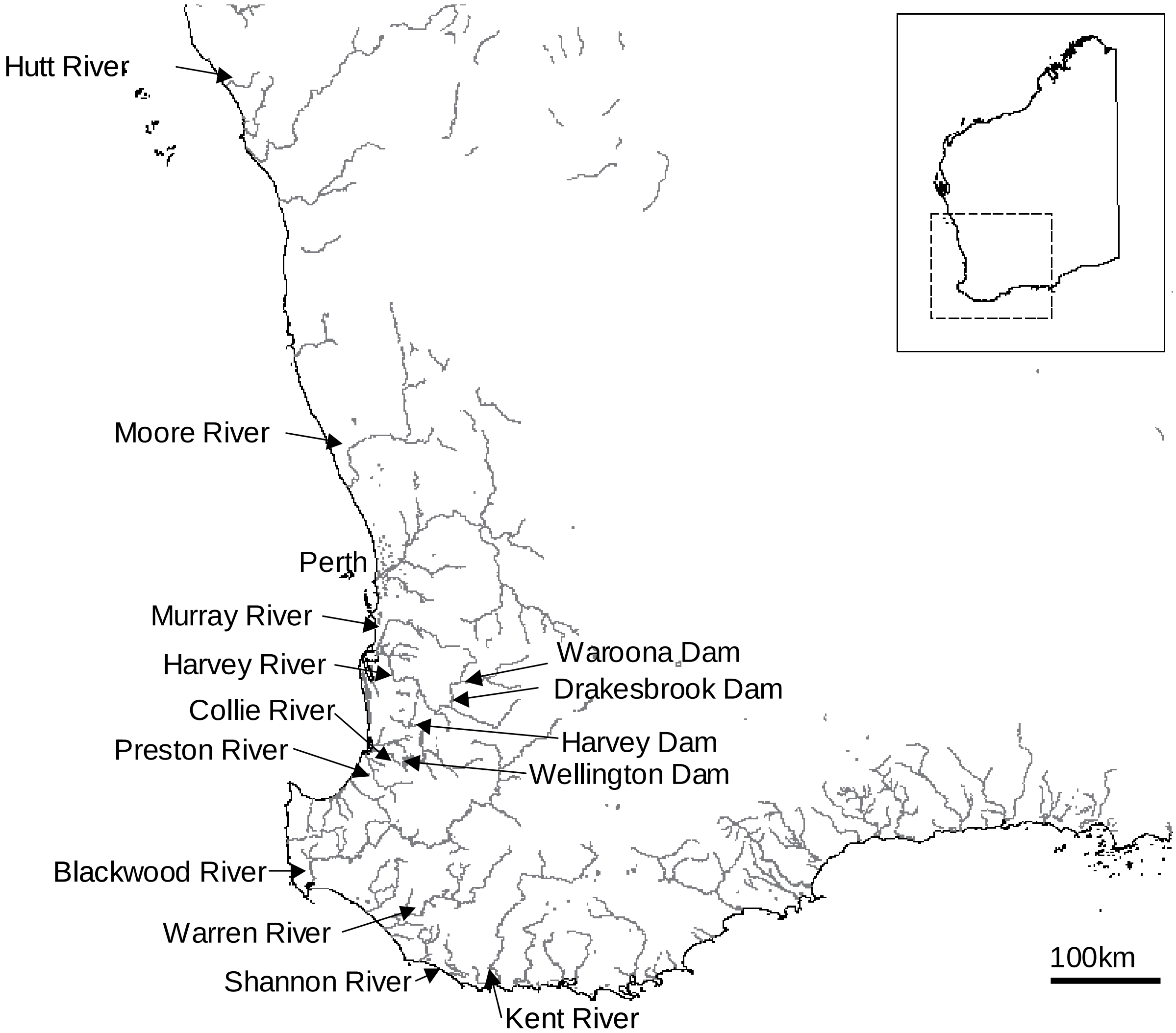


Figure 1. Location of sampling sites in the southwest of Western Australia.

Figure 2. Berried female *C. cainii*.

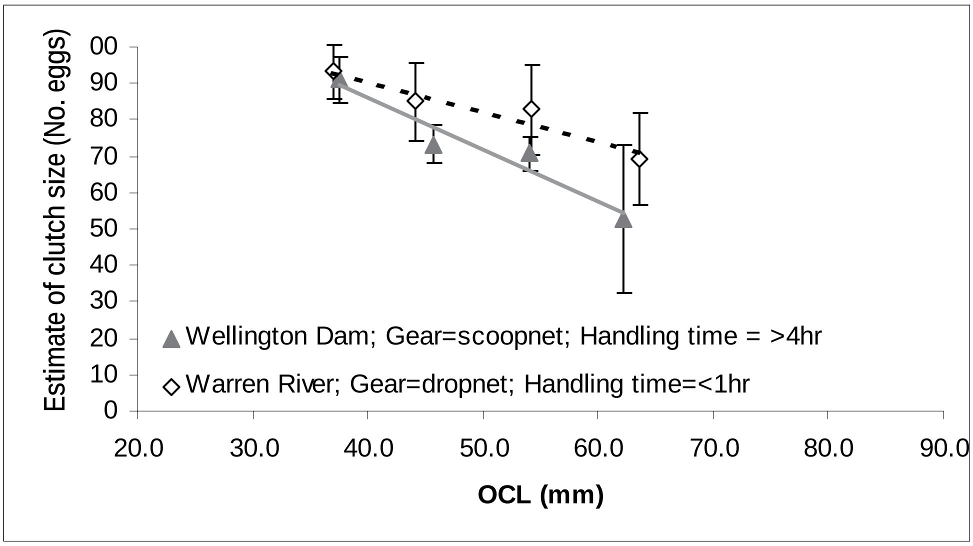


Figure 3. Relationship between size (10 mm OCL size classes) and visual estimation of clutch size of *C. cainii* in Wellington Dam and Warren River.

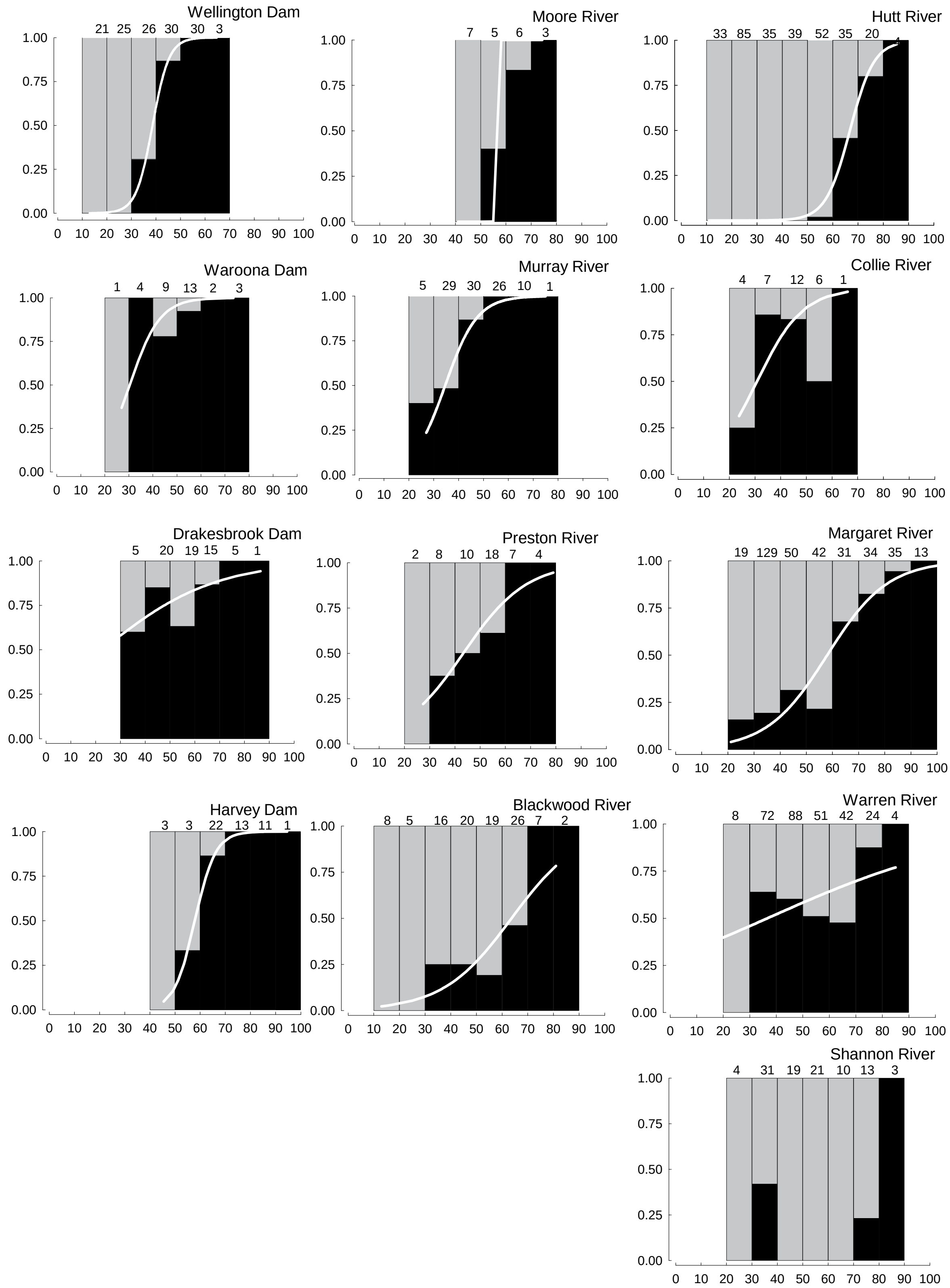
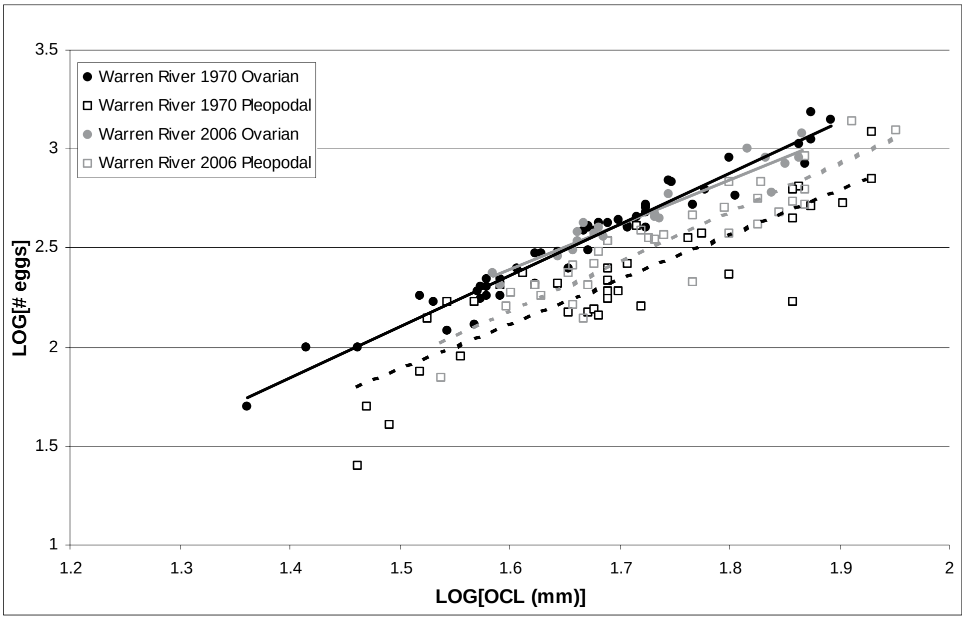


Figure 4. Percentage contributions of mature *C. cainii* females in sequential 10 mm OCL size classes, with the sample size shown above each 10 mm size class. Logistic regressions were fitted to the percentage of mature female *C. cainii* at different OCLs in dams and rivers in southwestern WA. Data for Hutt River was taken from Beatty et al. (2004).

(a)



(b)

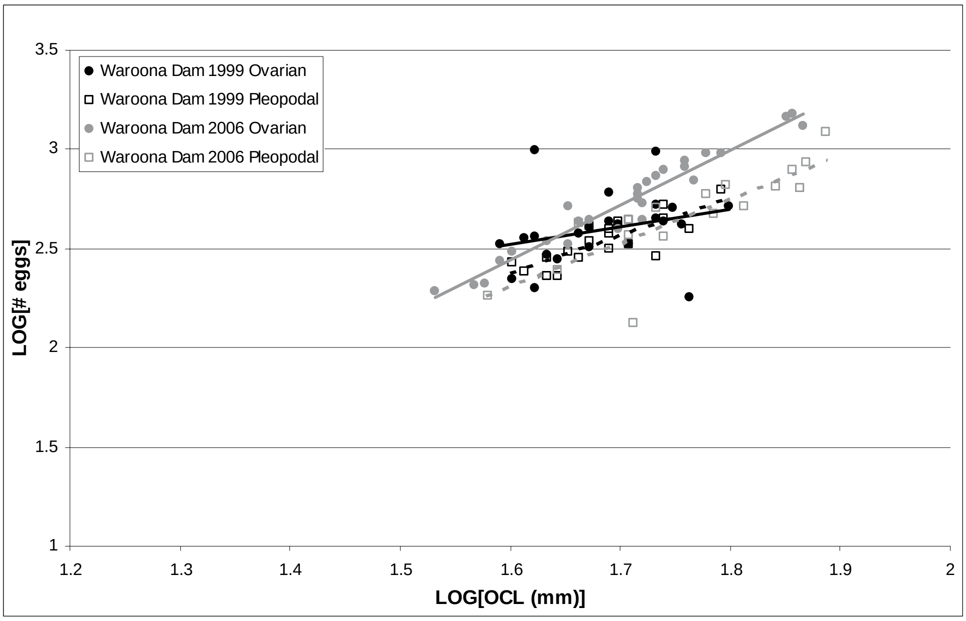
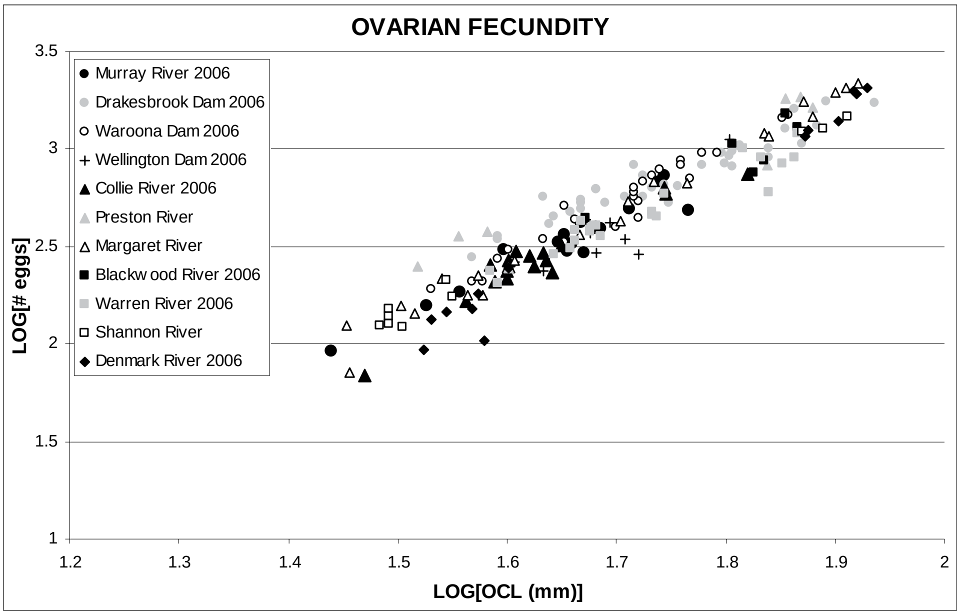


Figure 5. Temporal variation in ovarian and pleopodal fecundity of *C. cainii* in Warren River (a) and Waroona Dam (b). Data for Waroona Dam 1999 was taken from Beatty et al. (2003).

(a)



(b)

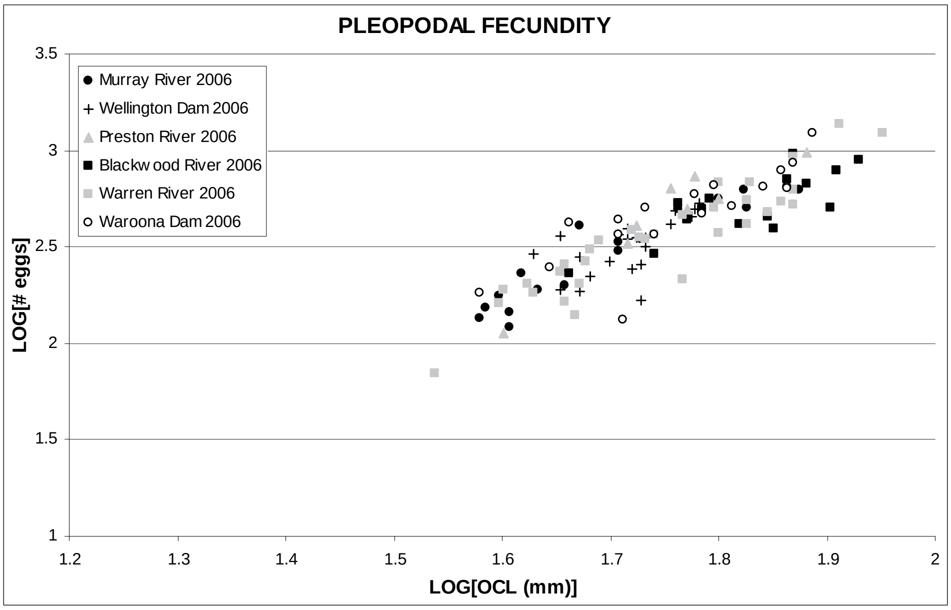


Figure 6. Ovarian (a) and pleopodal (b) fecundity of *C. cainii* in dams and rivers throughout the southwest of Western Australia.

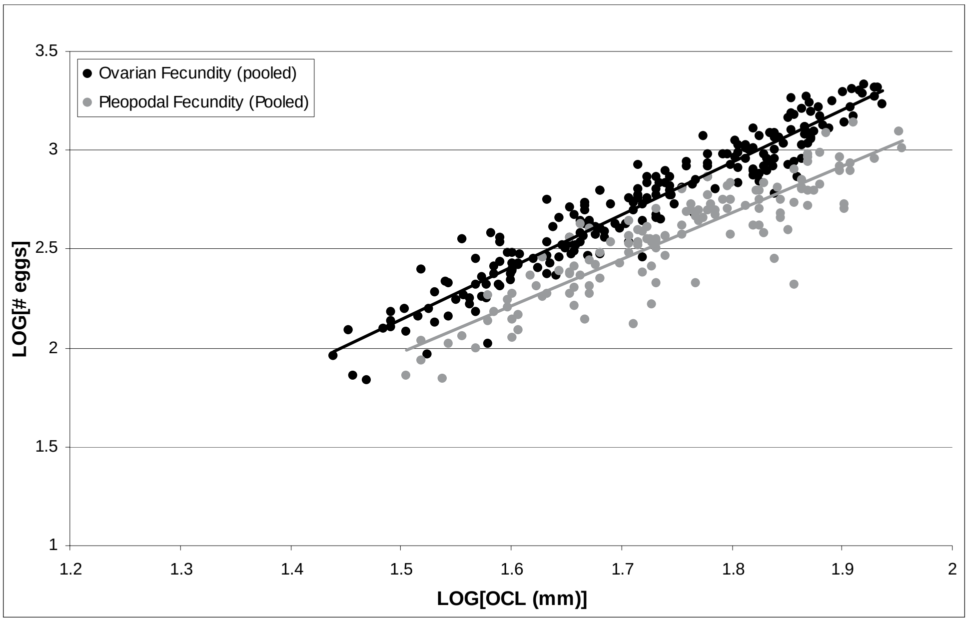


Figure 7. Comparison of ovarian and pleopodal fecundity for *C. cainii*.

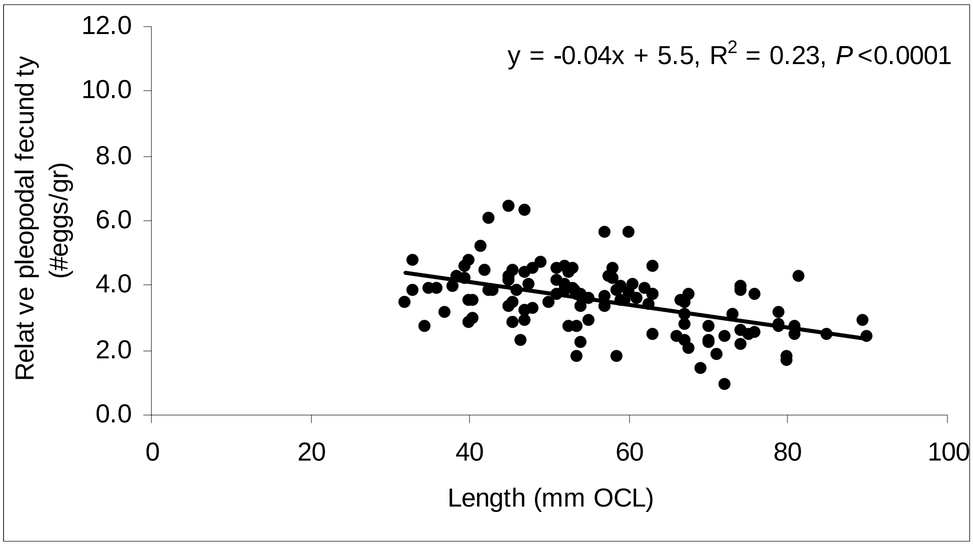


Figure 8. Relationship between relative pleopodal fecundity (#eggs/g body weight) and size (mm OCL) in *C. cainii* .

7.0 Estimating marron (*Cherax cainii*) densities in rivers and dams: influence of sampling method, habitat and vertical distribution

Martin de Graaf and Stephen Beatty

7.1 Introduction

Obtaining reliable data on marron abundance and population structure in rivers and dams within the Recreational Marron Fishery (RMF) is of crucial importance for its sustainable management. Such information is essential on order to quantify the impact and performance of management measures like changes in minimum legal size, gear restrictions, bag limit and season length. However, obtaining accurate estimates of freshwater crayfish populations is notoriously difficult and highly dependent on sampling method and habitat (France et al. 1991, Lamontagne and Rasmussen 1993, Rabeni et al. 1997, DiStefano et al. 2003, Dorn et al. 2005).

Substrate (i.e. benthic habitat type) is known to structure freshwater crayfish populations and effects, for example, density, growth rates, length-frequency distribution, predation and recruitment success (France et al. 1991 and references therein). Length-frequency distributions are drastically influenced by habitat (France et al. 1991) and inter and intra lake comparisons of growth dynamics should therefore be made from crayfish collected from similar high quality complex substrate like rocky habitat (France et al. 1991). Furthermore, freshwater crayfish often have a variable distribution along a depth gradient (Lamontagne and Rasmussen 1993) and/or exhibit seasonal vertical migration regulated by abiotic parameters like temperature (Skurdal et al. 1988).

The influence of different sampling methods (e.g. visual surveys, quadrat samplers, baited traps, hand nets, electrofishing) on estimates of freshwater crayfish population size distribution and densities have been studied in a variety of habitats such as rivers, lakes and wetlands (France et al. 1991, Lamontagne and Rasmussen 1993, Rabeni et al. 1997, DiStefano et al. 2003, Dorn et al. 2005). Underwater visual surveys (e.g. quadrats, belt-transects, timed counts) have been used successfully to determine freshwater crayfish densities in lentic environments (Davies 1989, France et al. 1991, Olsen et al. 1991, Lamontagne and Rasmussen 1993). Overall, stratified sampling based on distinct habitat types using area-based (e.g. quadrat, transect) methods, provide the most reliable estimates of freshwater crayfish densities (Davies 1989, Lamontagne and Rasmussen 1993, Dorn et al. 2005).

The effects of substrate type, vertical distribution and sampling method, on marron population dynamics or sample composition have received limited attention (e.g. Molony and Bird 2002). The aim of the current study was (a) to review and compare traditional sampling protocols (i.e. scoop net, drop net) for marron sampling with baited traps and underwater visual surveys, and (b) to investigate the effect of substrate and water depth on marron population dynamics in order to (c) determine the most appropriate sampling method to be used in developing an index of (relative) abundance.

7.2 Materials and Methods

Sampling methods: scoop-net

In dams, scoop nets (Fig. 1a) have traditionally been used to monitor reference populations of marron (Molony et al. 2002; Molony and Bird 2002). A scoop-net has a smaller mesh (25 x 30 mm) than a legal marron scoop-net (28 x 130 mm) to allow sampling of just-undersize marron (Fig. 1). One kilometre of bank is baited with a standard mixture of chicken layer-pellets and blood and bone fertiliser. At sunset, a handful of bait is placed every 10 m along the bank in water less than 0.5 m deep. Three passes are made along the bank at hourly intervals. All marron captured on the 100 baits during a pass are retained (pooled) in the same bin. This technique mimics the techniques employed by recreational fishermen, with the exception to the distance baited (recreational fishermen usually bait less than 500 m). On completion of a nights sampling, all marron within each pass are measured to the nearest 0.1 mm orbital carapace length (OCL) and sexed.

Sampling methods: drop-net

In rivers, drop nets have traditionally been used to monitor reference populations of marron (Molony et al. 2002, Molony and Bird 2002). A drop net has an upper and a lower wire hoop, each 60 cm in diameter, with netting stretched across the lower hoop and the two hoops are joined by a ca 20 cm high cylinder of netting (Fig. 1b: Morrissy 1970). Four short cords ascend from the upper hoop to a small cork above which there is a 5 m hauling rope with a buoy. When a net is dropped into the water and settles onto the bottom, the upper hoop falls down onto the lower hoop, giving marron easy access to the centrally situated bait. The drop-nets (Fig. 1) used for research have a smaller mesh size (5 x 5 mm) than legal drop-nets (80 x 32 mm, Morrissy 1989). The standard bait mixture, i.e. chicken layer pellets mixed with blood and bone fertiliser, as used for scoop-netting in dams is placed into a bait basket in the middle of the drop-net. In a river, 15 baited drop-nets are set in an overlapping pattern in maximum 5 m deep water at sunset. The nets are lifted three times at hourly intervals. All marron captured with the 15 drop-nets during one pass are retained (pooled) in the same bin. On completion of a nights sampling, all marron within each pass (15 drop net catches pooled) are measured to the nearest 0.1 mm OCL and sexed.

Sampling methods: black box trap

Commercially available, rectangular box traps (60 cm length x 45 cm width x 20 cm height, 10 mm square mesh; Fig. 1) were used to sample marron in both rivers and dams up to a depth of 35 m. The traps had a funnel-like entrance spanning the width of the trap on each site. The standard bait mixture was placed into a bait basket in the middle of the trap. Traps were deployed at the end of the afternoon (16:00-18:00) at 20 m intervals and were recovered the following morning (8:00-12:00). All marron captured in each individual trap were measured separately to the nearest 0.1 mm OCL and sexed.

Sampling methods: visual survey

Estimating densities of marron using belt-transects was trialled in Waroona Dam (Fig. 2). In September 2005 and April 2006, 100 m belt-transects were placed parallel to the shore in water less than 4 m deep over both rock and sand substrate. After sunset (between 20:00 and 22:00) two divers, one on each side of the transect line, slowly swam the length of the transect line with dive lights and recorded the number and size (10 mm size classes) of marron within 1m of the line (Davies 1985). After completion of the visual surveys at a site, baited black box trap were deployed the following night at the same location to investigate the reliability of traps catches as indices of marron abundance.

Vertical distribution

The depth distribution of marron was investigated in Wellington Dam (Fig. 2) by deploying traps perpendicular to the shore at one site (depth range 1-35 m) between April 2005 and May

2006. Seven fixed depth stations were selected based on full storage capacity: A=35 m, B=27.5 m, C=22.5 m, D=17.5 m, E=12.5 m, F=7.5 m, G=<2.5 m. Sampling details: 28/4/05 ten traps each at stations B-F; 2/6/05 ten traps each at stations B-F; 5/8/05 eight traps each at stations A-F; 13/10/05 seven traps each at stations A-G; 15/12/05 seven traps each at stations A-G; 2/3/06 eight traps each at stations A-G; 2/5/06 nine traps each at stations A-F. Baited traps were deployed in the late afternoon (16:00-18:00) at 20 m intervals and were recovered the following morning (8:00-12:00). Marron captured in each trap were measured to the nearest 0.1 mm OCL and sexed. Females were classified as ovigerous or non-ovigerous before being returned to water at the same site/depth where the trap was deployed. Temperature (ºC) and oxygen (mg/l) was recorded on each sampling occasion, except April 05 and August 05, at 1 m intervals.

Index of abundance

In October/November 2006 relative abundance of adult marron was determined in the three large public dams and five rivers. Wellington Dam, Waroona Dam and Harvey Dam traditionally receive a high degree (70-80%) of the total dam effort (Chapter 4). Similarly the Warren River, Blackwood River, Preston River and Murray River are the most popular marroning rivers receiving more than 60% of the total river effort (Chapter 4). The Shannon River on the other hand is a relatively pristine river, flowing through protected forested throughout the length of the river. In 2007 the Shannon River was closed to all fishing activities. The following sampling effort was allocated at each location (Fig. 2): Waroona Dam 1/11/06 46 traps 4 sites; Harvey Dam 2/11/06 41 traps 4 sites; Wellington Dam 3/11/06 45 traps, 4 sites; Murray River 19/10/06 40 traps 2 sites; Warren River 24/10/06 50 traps 1 site; Shannon River 25/10/06 35 traps 3 sites; Blackwood River 26/10/06 40 traps 2 sites; Preston River 27/10/06 35 traps 3 sites. Baited traps were deployed in the late afternoon (16:00-18:00) at 20 m intervals in water less than 5 m deep and were recovered the following morning (8:00-12:00). Marron captured in each trap were measured to the nearest 0.1 mm OCL and sexed. Temperature (ºC), oxygen (mg/l), pH and conductivity (mS/cm) were recorded at each site at 0.5 m depth. Vertical transparency (m) was measured using a Secchi disk.

7.3 Results

Sampling methods: size distribution and sex ratio

Length-frequency distributions of marron sampled in the Warren River with drop nets or traps were highly similar (Fig. 3a). A similar pattern was observed in Wellington Dam with little difference recorded in length frequency distributions of marron sampled with trap or scoop nets over sand substrate (Fig. 3b). Marron smaller than 30-35 mm OCL were rare in all samples regardless which method was used, despite the fact that traps easily are capable of retaining freshwater crayfish <30 mm OCL as illustrated in Figure 4.

Sampling method did have a pronounced effect on sex ratios. In both Wellington Dam and the Warren River the sex ratios of the marron samples collected late October –early November 2005 with traps were more biased towards males (female:male ratio 1:2.9 Warren River and 1:3.9 Wellington Dam) than the samples collected with drop nets (1:1.6) or scoop net (1:1.4). The sex ratios of marron samples collected with traps changed throughout the year (Fig. 5). The highly male biased sex ratios during the breeding season (Oct-Dec) are mainly caused by a decrease in female CPUE in both the Warren River and Wellington Dam. During these months (ovigerous) females appeared to be less inclined to enter the traps.

Sampling methods: indices of abundance

Trap catches and visual surveys appeared to be correlated when conducted over sand substrate. No significant difference (χ^2-test, $P = 0.8$) was found between the trap: visual (1.9 marron/trap : 0.5 marron 100 m^2) ratio in September 2006 and April 2006 (4.6 marron/trap 1.9 marron 100 m^2). Both estimates of marron abundance were roughly three times higher in April 2006 compared to September 2006. However, the significant decrease in water level from 81% capacity in September 2005 to 62% capacity in April 2006, concentrated Waroona's marron population over a considerable smaller dam volume/surface area.

As the distance of attraction of bait for marron in still water has previously been found to be ~10 m (Morissy 1975), the effective sampling area of a trap (radius ~10 m) was estimated as ~300 m^2. Based on these assumptions absolute marron densities (# marron per 100 m^2) in the littoral zone (<5m depth) over sand substrate using traps was ~0.6 marron/100 m^2 in September 2005 and 1.5 marron/100 m^2 in April 2006. These values are similar to the estimates of densities as determined by the visual surveys, i.e. 0.5 marron/100 m^2 in September 2005 and 1.9 marron/100 m^2 in April 06. Based on these results trapping data collected over sand substrate in dams appeared to be useful as indices of both relative and absolute density.

Habitat type

Several clear and consistent patterns emerged from trapping programs and/or visual surveys over rock and soft substrate in Waroona Dam (Figs 6 and 7), Harvey Dam (Fig. 8) and Drakesbrook Dam (Fig. 9) between 2005 and 2007. Firstly marron densities were repeatedly higher over rock substrate than soft substrates. Secondly, a wider size range was usually observed over complex rocky substrate with a higher abundance of juvenile and small adult marron. On average fewer but larger sized marron were collected over soft substrate. Furthermore, the mean density of ovigerous females was significantly higher over rock substrate compared with sand substrate in Waroona Dam (Fig. 10).

Vertical distribution

Between April 2005 and October 2005 water levels rose by almost 10 meters in Wellington Dam (Fig. 11). In October 2005, Wellington Dam reached maximum capacity and was overflowing. During these months marron followed the rise in water level and although marron were observed to occur in the whole water column up to 35 m deep, throughout the year the highest densities of marron were found in the littoral zone (<10 m depth). In December 2005 a thermocline had formed at about 10m depth. The thermocline had a strong effect on the distribution of berried females as none were observed below the thermocline.

Index of abundance

The results of the 2006 marron stock assessment are presented in Table 2 and Figures 12 and 13. Several differences in environmental characteristics were observed among the water bodies (Table 2). The Shannon River is the only river studied completely surrounded by State Forest and had a lower water temperature, pH and vertical transparency than the other systems. The low vertical transparency was most likely caused by the natural high amount of tannin rather than turbidity. The Murray River and Blackwood River were moderately saline, Wellington Dam and the Warren River were marginal while only Waroona Dam, Harvey Dam, Preston River and Shannon River were classified fresh based on their salinity levels.

Considerable variation was also recorded for CPUE and size of marron in each system (Figs. 12, 13). Harvey Dam produced the lowest CPUE (3.2 marron/trap) but the largest average size

(77.2 mm OCL). The highest average (27.8 marron/trap) and maximum CPUE (66 marron) was recorded for Wellington Dam. In contrast to Harvey Dam (90%) only a small proportion (11%) of the Wellington Dam sample was of legal size. Among the samples collected in the rivers the Warren River (45%), Blackwood River (53%) and Preston River (36%) all contained a large proportion of legal size marron. The Warren River also produced the second highest CPUE (20.3 marron/trap) of all sampled water bodies. On the other hand the trap samples collected from the Murray River (7% legal size) and Shannon River (16% legal size) contained predominantly sub-legal size marron.

7.4 Discussion

Sampling methods: comparison scoop net, drop net and trap

Historically, marron research surveys have been conducted using scoop nets in dams and drop nets in rivers. One drawback of using different methodologies in rivers and dams was illustrated in Chapter 6. The development of a standard method that can be used in both rivers and dams is highly desirable to increase the quality of marron stock assessment data. Table 1 provides an overview of the most important advantages and disadvantages of scoop nets, drop nets and traps.

Like scoop nets and drop nets, traps also depend on bait attraction and therefore catch rates and catch composition for all three methods are expected to be biased toward large males and are possibly influenced by temperature, moulting stage, water level (‘dilution’) and moon cycle (Table 1). For example, in Waroona Dam (Fig. 6) the increase in marron densities in April 2006 compared to September 2005 was most likely due to the recruitment of marron into the sampling gear after the 2005-2006 summer growth period and the reduction in dam water level ‘concentrating’ the marron in April 2006 in a significantly smaller volume of water (September 81% capacity, April 62% capacity). Stock assessments need to occur roughly at the same time each year and environmental parameters like water temperature and water level need to be recorded accurately to reduce or compensate for these potential sources of variation.

Despite the shared drawbacks of the three methods, traps have several important advantages over scoop nets and drop nets. Most importantly, trap catches are not affected by weather, water turbidity or skill of the operator. The catch rates of scoop nets are negatively affected by weather (wind and rain) and water turbidity, which decrease visibility and catch rates. Weather and turbidity have limited effect on trap catches. Catch rates of scoop nets are also highly correlated to the experience and skill of the operator. An important and desirable characteristic of trapping is that catches are independent of the skill of the operator. Drop nets are, to a lesser extent, affected by weather, turbidity and the experience of the operator. Any hesitation in pulling the drop nets or a noisy approach of the drop net will scare the marron off the net and subsequently reduce catches (C. Bird, personal communication). Furthermore, unlike drop nets and traps, the operator using a scoop net actively selects which animal is caught. Scoop nets can only be used near the shore on sandy habitat, while traps and to a lesser extent drop nets, can be used at different depths and habitats.

Drop nets and scoop nets are ‘active’ methods of collecting animals, limiting operators to sample only one site while working late at night. A major advantage of traps is that they can easily be set at several sampling stations in a river or dam and can be collected the following day. From an occupational health and safety point of view this is a major improvement, as a trapping program does not require staff to spend long hours at night, walking large distances on unstable and uneven banks of rivers and dams.

Traditionally, all marron caught by scoop or drop nets in a section of a river or dam were mixed and stored in plastic bins before being measured and sexed at the end of the evening. The data collected in this way were presented as a total (pooled) number of marron caught at a certain site in a certain year (eg. Waroona Dam 2001, 256 marron), without any option to quantify variation, required to properly analyse differences in densities between seasons.

A simple and robust trapping program recording CPUE, size, sex etc. per trap at the will generate a reliable index of relative abundance of marron and provide a quality data set to analyse temporal and spatial variation in population dynamics. Spatial (Figs. 6-10) and temporal (Fig. 5) variation in catchability is high, it is therefore of utmost importance to sample the same sites in each water body in the same season (Oct-Dec). Furthermore, environmental parameters (water level, water flow, temperature etc) need to be carefully recorded and if required trap CPUE data will need to be standardised before inter-annual comparisons in relative abundance in any particular river or dam.

The size selectivity of the three methods is similar (Fig. 3), allowing direct comparison of historic (scoop net, drop net) with contemporary (trap) length-frequency distributions to determine long-term changes in population structure despite a change in methodology.

Sampling methods: traps as indices of abundance.

Although traps provide a more reliable index of abundance compared to scoop nets and drop nets, it is not the best or most ideal method. Area-based (underwater) surveys (e.g. quadrats, belt-transects, timed counts, throw traps) are generally considered to generate the most reliable estimates of freshwater crayfish abundance (Davies 1989, France et al. 1991, Olsen et al. 1991, Lamontagne and Rasmussen 1993, Dorn et al. 2005). Underwater sampling on the other hand is expensive, time-consuming and not practical in the large, deep and turbid rivers in the southwest of Western Australia.

Trap catches have been shown to be positively and significantly correlated to visual surveys (Collins et al. 1983, Olsen et al. 1991), demonstrating their suitability as indices of abundance for adult freshwater crayfish (Momot 1967). In Waroona Dam (Fig. 6), trap data were reliable indices of visual survey data but only on soft substrate. Traps function optimally when placed on an even substrate to provide good access. Despite the higher densities of marron on rock substrate in Waroona Dam, the trap catches most likely underestimated marron densities due to the uneven substrate, which restricted trap access. Overall, traps appeared to be reasonable indices of relative and even absolute (soft substrate in dams) abundance, but further 'truthing', (i.e. comparing trap catches with visual surveys), in dams and suitable rivers, is required.

Marron distribution: vertical distribution and habitat type

In lentic environments freshwater crayfish are most common in the littoral zone and vertical migration is strongly influenced by the presence of a thermocline (Skurdal et al. 1988, Davies 1989, Lamontagne and Rasmussen 1993). Vertical distribution and migration of marron in dams did not deviate from patterns described for American (*Orconectes virilis*, Davies 1989) and European (*Astacus astacus*, Skurdal et al. 1988) freshwater crayfish species. In Wellington Dam, marron densities decreased with depth and followed fluctuations in water levels (Fig. 11).

Freshwater crayfish populations are strongly structured by physical characteristics of the littoral substrate. For largely non-burrowing crayfish like marron the availability of structural shelters, such as crevices in rocks, is the critical resource bottleneck. Shelter provides protection against predation, including cannibalism, during vulnerable phases of crayfish life history like reproduction and moulting. Crayfish length-frequency distributions vary along a predictable gradient in relation to the proportion of hard (rocks, pebbles, boulders etc) and soft (sand, mud) substrate in an area. Areas with a high proportion of complex substrate contain higher densities of crayfish of a wide size range, including juveniles, while crayfish abundance over soft substrate is generally lower with a limited size range, (i.e. predominantly larger adult individuals) (Skurdal et al. 1988, France et al. 1991, Blake and Hart 1993, Kirjavainen and Westman 1999). This pattern was observed in Waroona Dam, Drakesbrook Dam and Harvey Dam (Figs 6-9). Regardless of which method was used (traps or visual surveys), higher (sub) adult (>30 mm OCL) marron densities were consistently observed over complex rocky habitat and fewer but larger marron over soft substrate in all three dams.

In Drakesbrook Dam (Chapter 8) visual surveys demonstrated that juvenile marron (<20 mm OCL) were restricted to rock substrate, with few juveniles observed on soft substrate. The distribution of juvenile marron in dams is probably strongly influenced by the distribution of ovigerous females. In Drakesbrook Dam densities of adult marron were higher over rock than soft substrate (Fig. 9) but more importantly, in Waroona Dam densities of ovigerous females (Fig. 10) were significantly higher over rock substrate. Furthermore, in Wellington Dam ovigerous females were found only in the littoral zone of the dam above the thermocline (Fig. 11). Similar vertical and horizontal (habitat type) distribution patterns of juvenile and ovigerous females were reported for the freshwater crayfish *Pacifastacus leniusculus* (Blake and Hart 1993).

These results have clear and straightforward implications for management initiatives to enhance the Recreational Marron Fishery in public dams. A large-scale artificial habitat project is currently being developed for Drakesbrook Dam (2008-2009). Based on the results of this study, the artificial reefs in Drakesbrook Dam will be constructed in the littoral areas of the dam in order to provide optimum and adequate shelter for ovigerous females and juveniles.

Index of abundance

Based on the results of the current review of the different sampling methodologies, the first new annual marron survey was conducted in 2006. Initially five rivers and three dams were surveyed using ~40 traps placed at 2-4 sampling sites per water body. Most water bodies differed considerably in CPUE, population structure (% legal individuals) and environmental characteristics (Figs 12, 13 and Table 1). In addition to providing solid baseline data on relative abundance and population structure, the simple and robust trapping program also generated data on reproductive biology (see Chapter 6). In 2008 the program will be extended from two to three weeks, increasing the number of dams (three to four) and rivers (five to eight).

Laboratory trails will be initiated to investigate retention of external T-bar tags and the effects of external T-bar tags on growth and survival in large, legal sized individuals (>55 mm OCL). Despite several drawback of external tags (see Chapter 9), T-bar tags have been successfully used in wester rock lobster (*Panulirus cygnus*) research to collect basic biological information (Melville-Smith and Chubb 1997, Chubb et al. 1999) Incorporating a large-scale tagging program in the annual stock assessment survey will hopefully provide much needed information on temporal and spatial variation of growth and mortality of legal-size marron in the field.

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Table 1. Factors influencing sample quality and catch rate of different marron sampling techniques.

	Scoopnet	Dropnet	Trap
Bait	**Dependent**	**Dependent**	**Dependent**
Water level	**Dependent**	**Dependent**	**Dependent**
Water temperature	**Dependent**	**Dependent**	**Dependent**
Sex-ratio	**Male biased**	**Male biased**	**Male biased**
Ovigerous females	**Under represented**	**Under represented**	**Under represented**
Size selection	**Biased to large individuals**	**Biased to large individuals**	**Biased to large individuals**
Moulting individuals	**Under represented**	**Under represented**	**Under represented**
Mooncycle	**High impact**	Moderate impact	Low impact
Turbidity (wind, rain)	**High impact**	**Moderate impact**	Limited impact
Objectivity			
Skill operator	**High impact**	**Medium-High impact**	Low impact
Selection marron by operator	**Subjective**	Objective	Objective
Labour intensive	**High**	Moderate	Low
Habitat (river and dam)	**Limited**	+/-	++
Water depth	**<1 m**	**5-10 m**	No limit
Costs			
Material	Very inexpensive	**expensive**	inexpensive
Labour (long hours)	**expensive**	**expensive**	inexpensive
OH&S			
Night- time driving	**Yes**	**Yes**	No
Walking uneven surface at night	**Yes**	**Yes**	No
Quality data (sample pooling, objectivity)	**Low**	**Low**	High
No. sites sampled per night	**1**	**1**	2-4
Suitability "relative abundance index"	**Poor**	**Reasonable**	**Reasonable to Good**

Table 2. Abiotic parameters and classification of water salinity (following Hillel 2000 and Mayer et al. 2005) of the water bodies sampled during the 2006 annual marron stock assessment.

Location	Conductivity (mS/cm)	Salinity Status	Temperature (ºC)	pH	Secchi (m)	Oxygen (mg/l)
Waroona Dam	0.22	Fresh	19.5	7.5	2.8	12.0
Harvey Dam	0.32	Fresh	19.7	7.5	2.8	10.4
Wellington Dam	1.90	Marginal	20.2	7.5	7.5	13.0
Murray River	8.06	Moderately Saline	18.4	7.7	1.7	9.5
Preston River	0.96	Fresh/Marginal	18.9	7.2		9.5
Blackwood River	5.65	Moderately Saline	19.7	7.2	2.4	9.9
Warren River	1.54	Marginal	18	7	1.8	8.6
Shannon River	0.34	Fresh	15.3	5.9	0.4	8.5

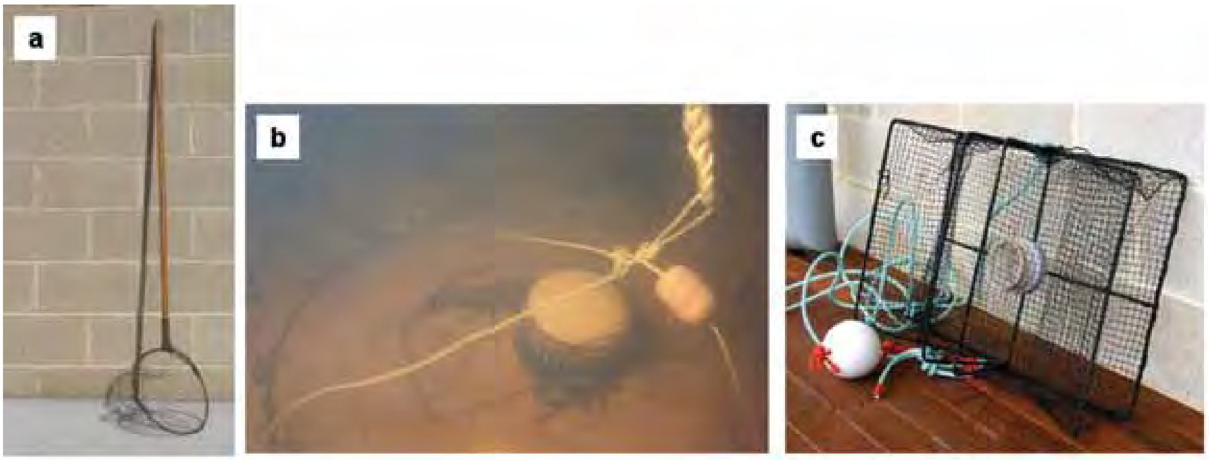


Figure. 1 Marron sampling gear: (a) scoop net, (b) drop net and (c) black box trap.

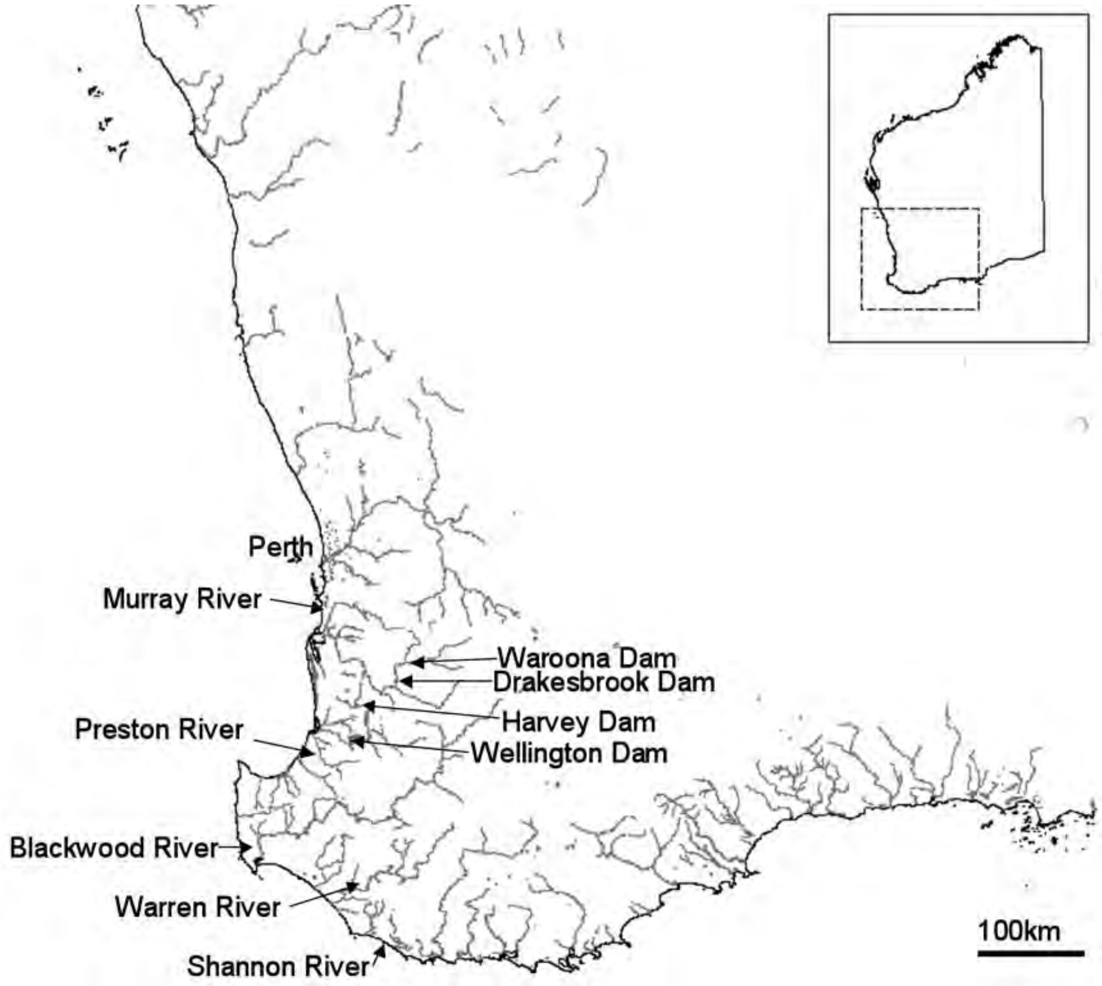
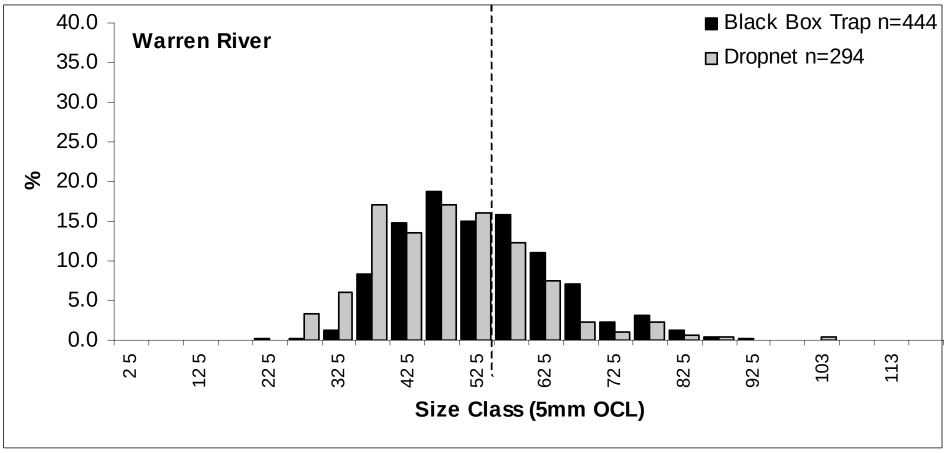


Figure 2. Locations of rivers and dams sampled for marron in southwest Western Australia.

(a)



(b)

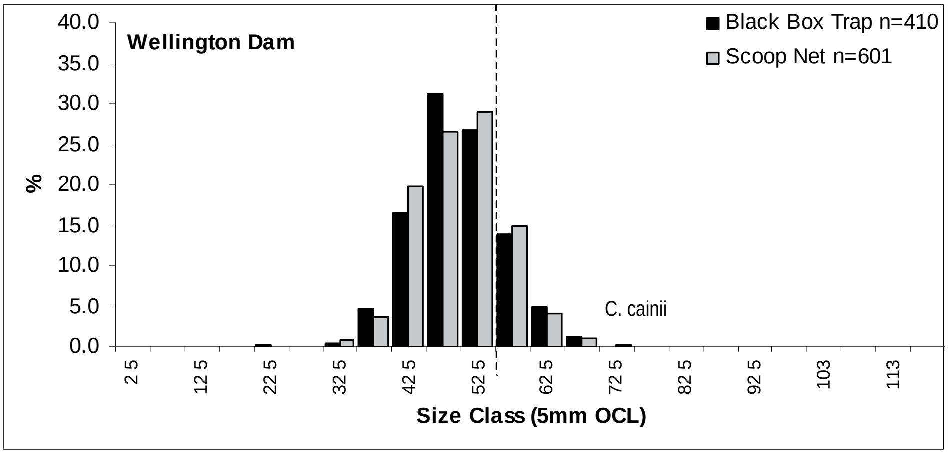


Figure 3. Comparison of length-frequency distributions of *C. cainii* sampled with (a) traps and drop nets in the Warren river and (b) traps and scoop net in Wellington Dam.

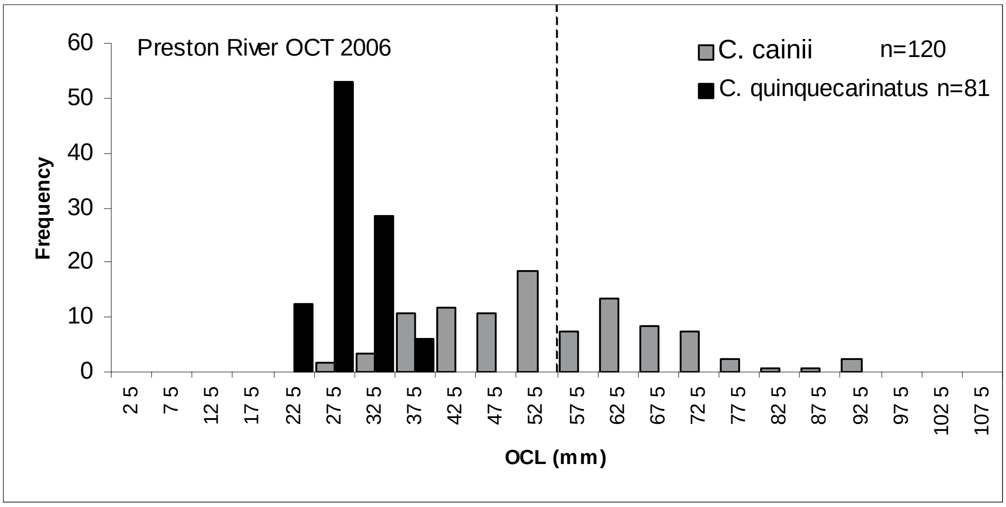


Figure 4. Comparison of length-frequency distributions of *C. cainii* and *C. quinquecarinatus* sampled with traps in the Preston River.

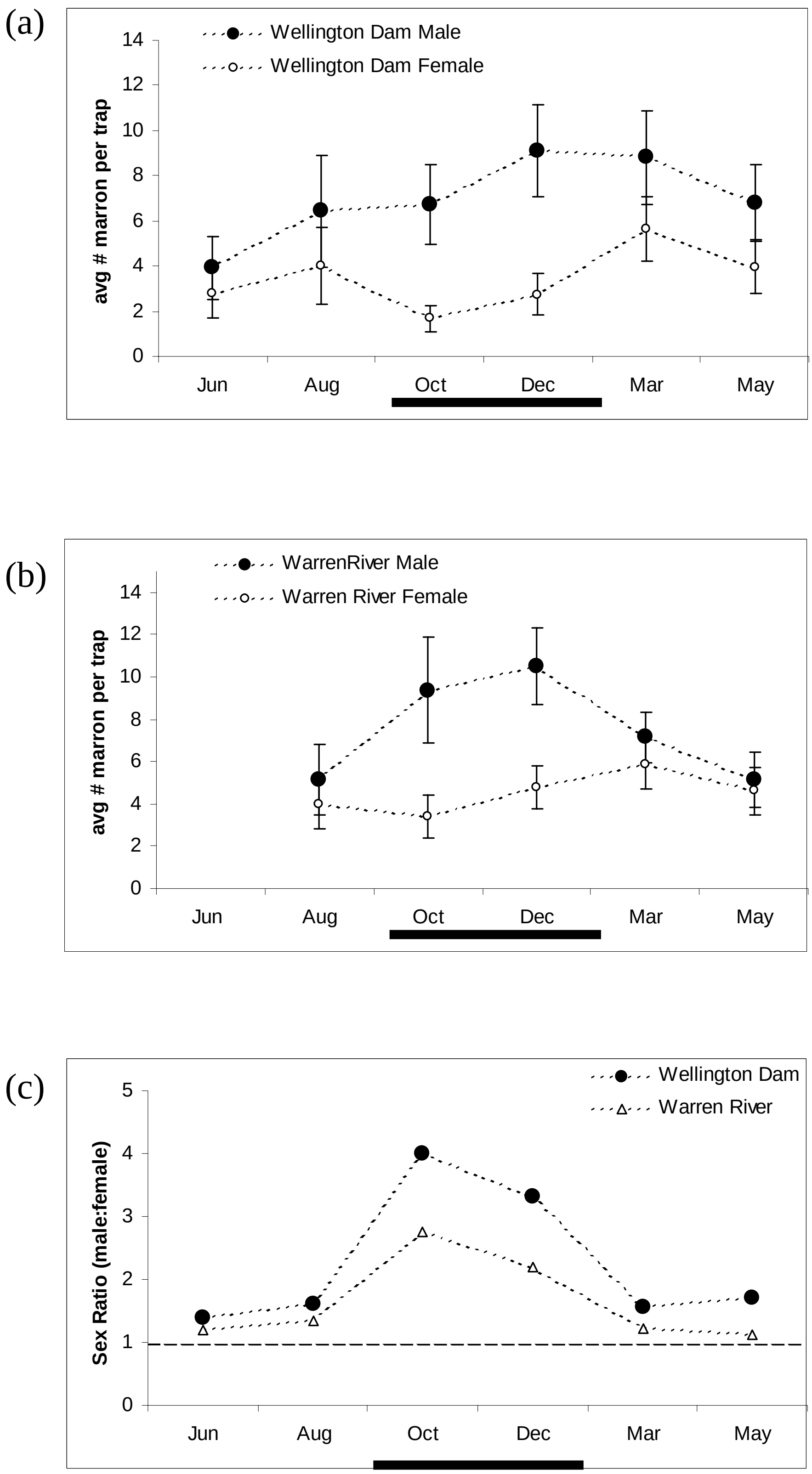
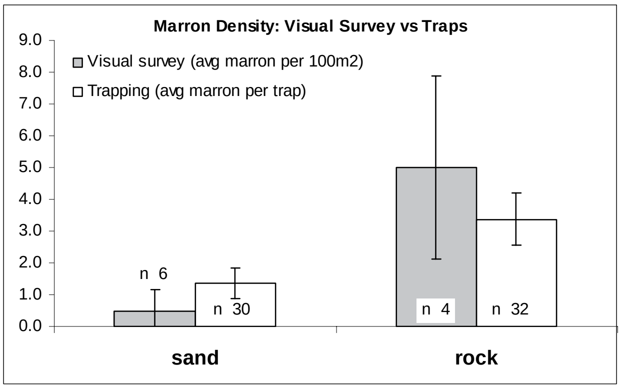


Figure 5. Male and female CPUE per trap in Wellington Dam (a) and Warren River (b) and temporal (monthly) changes in sex ratios at both indicator sites (c). Horizontal bar indicates breeding period, error bars are 95% confidence intervals.

September 2005

(a)



April 2006

(b)

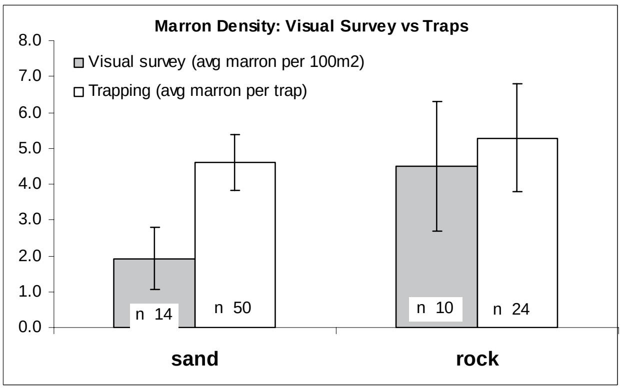


Figure 6. Effect of habitat on marron densities. Note that both traps and visual surveys show similar patterns in marron abundance (Note: y-axis indicates average number of marron recorded in visual survey or trapped). Error bars represent 95% confidence intervals.

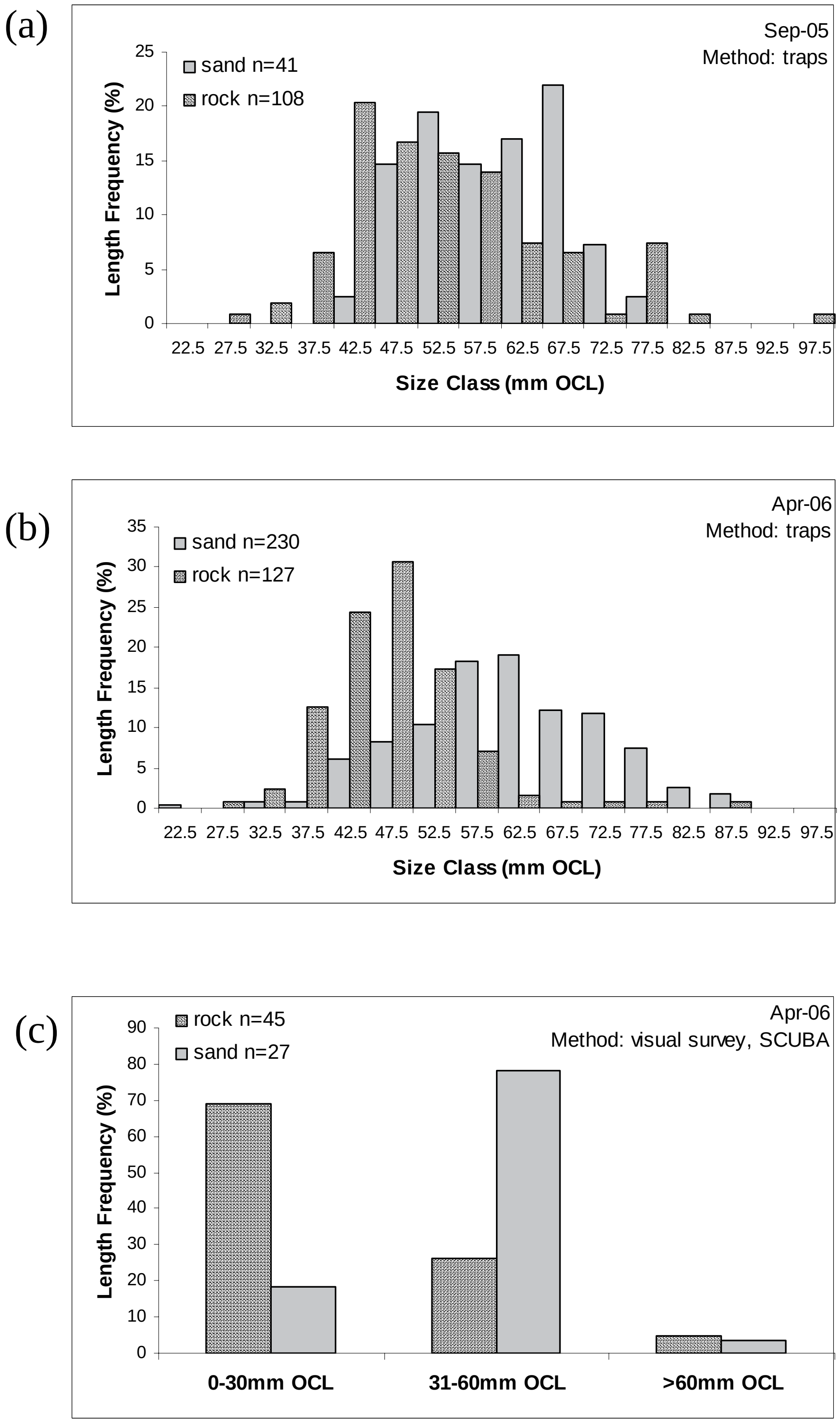


Figure 7. Comparison of length-frequency distribution Effect of habitat (sand vs. rock) on population size structure in Waroona Dam. Note that traps (a, b) and visual surveys (c) showed the same pattern: sandy habitat mostly contained large (sub)adult marron while rocky habitat contained large (sub)adult and many juvenile marron.

(a)

(b)

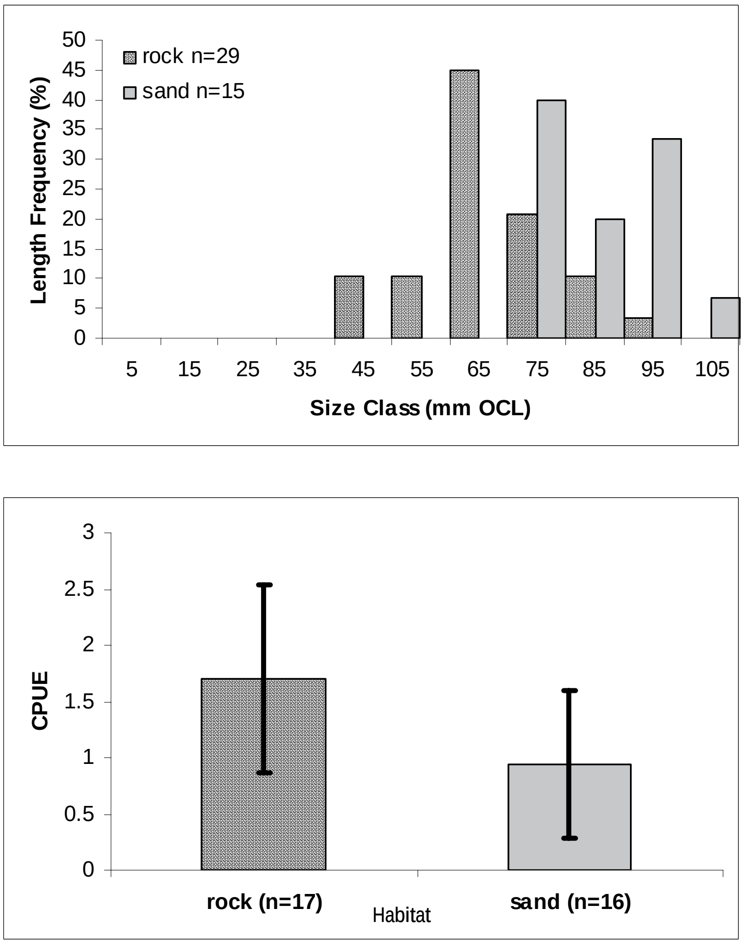


Figure 8. Comparison of (a) length-frequency distributions and (b) densities of *C. cainii* sampled with traps over rock and sand substrate in Harvey Dam (June 2005).

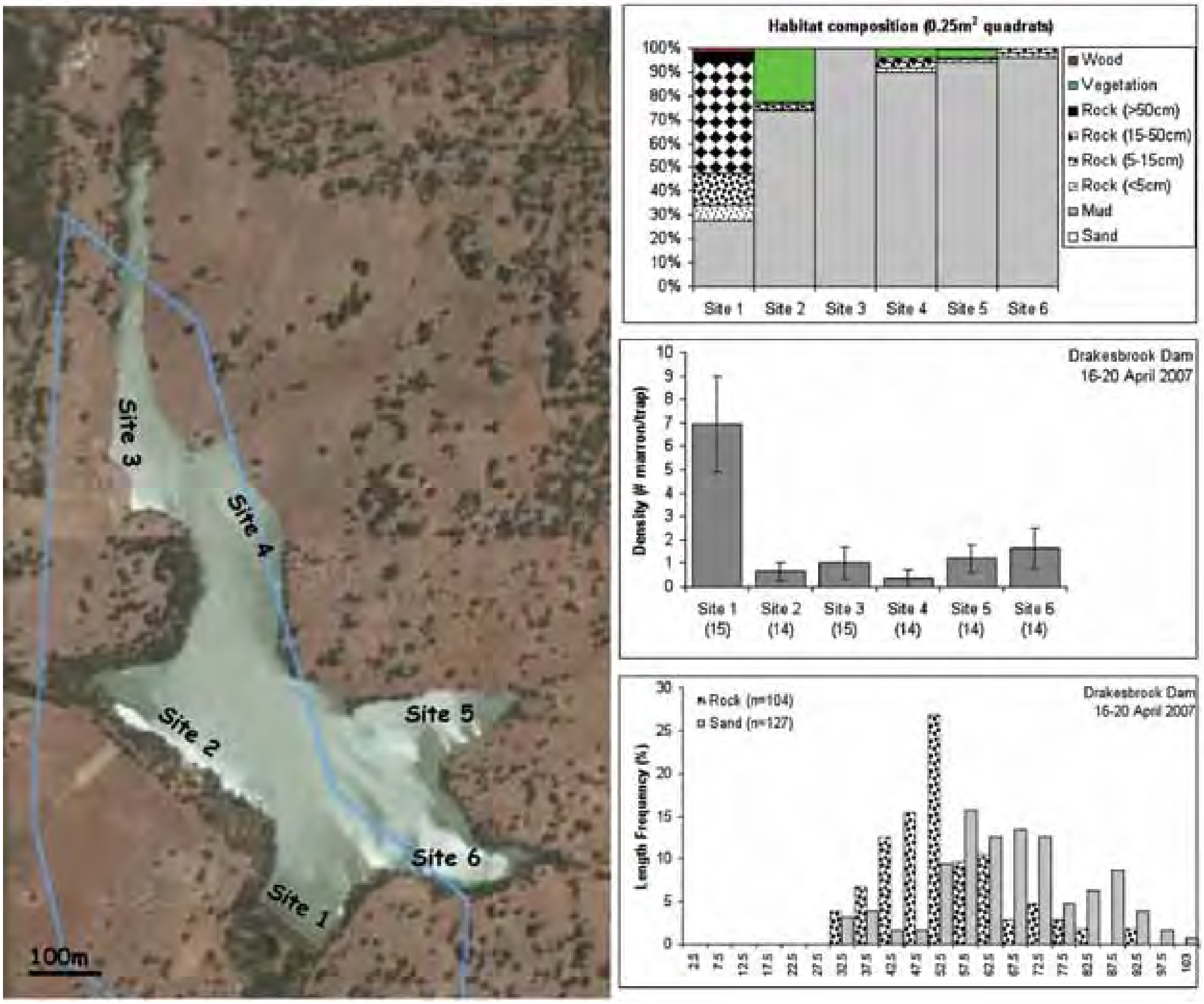


Figure 9. Comparison of CPUE and length-frequency (mm OCL) distributions of *C. cainii* collected over areas of rock (Site 1) and mud (Sites 2-6) substratum in Drakesbrook Dam (April 2007). Error bars represent 95% confidence intervals.

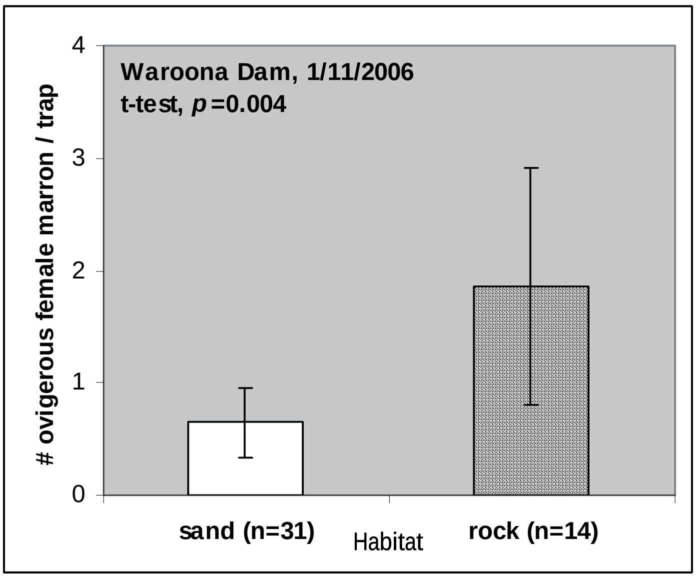


Figure 10. Comparison of CPUE of ovigerous *C. cainii* collected with traps over rock and sand substrate in Waroona Dam . Error bars represent 95% confidence intervals.

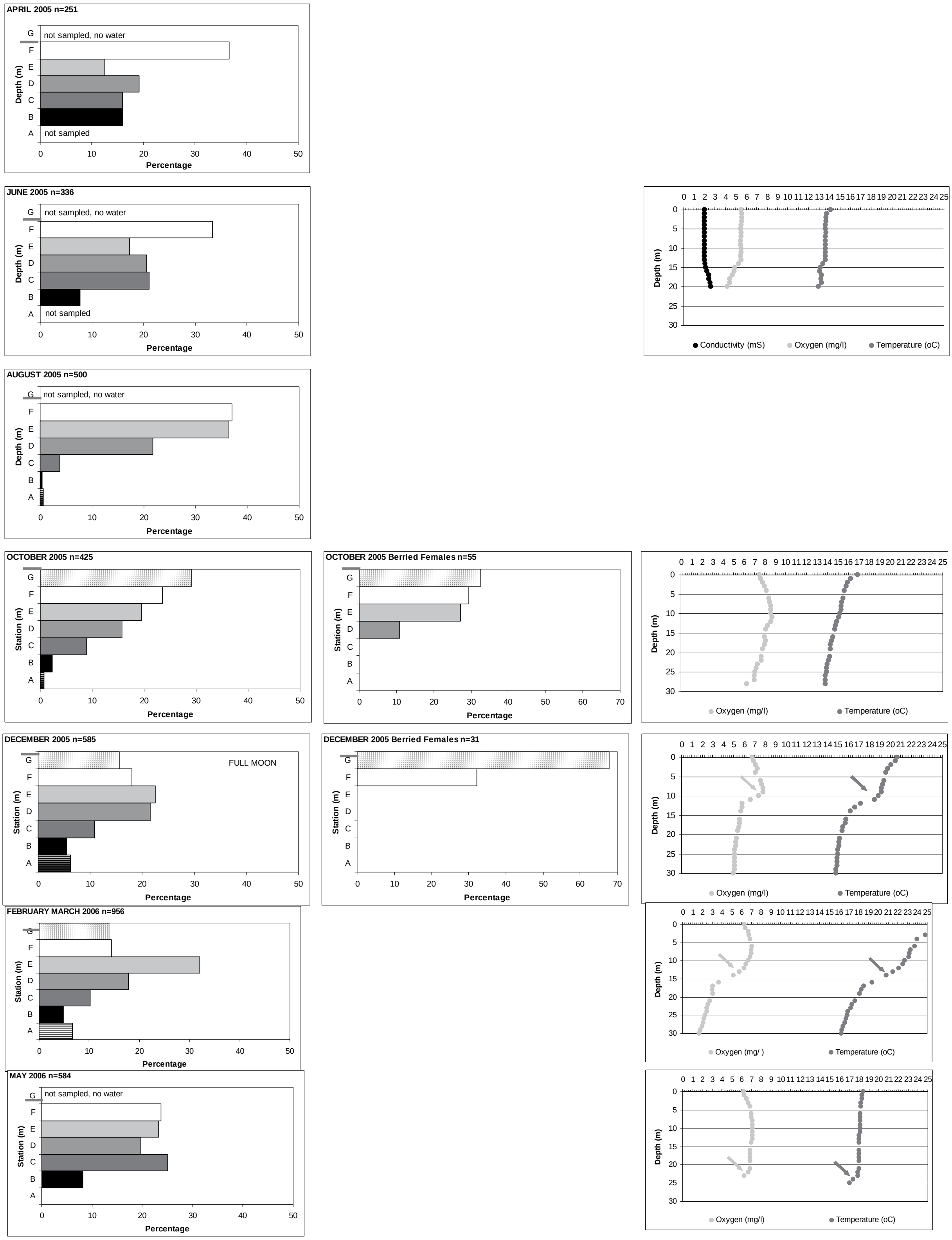


Figure 11. Seasonal changes in abiotic parameters and vertical distribution of marron in Wellington Dam. Arrows indicate approximate location of thermocline and blue lines indicate approximate dam water level. Depth distribution of the fixed sampling stations in October 2005 (dam at maximum capacity); A = 35 m, B = 27 m, C= 22 m, D = 17 m, E = 12 m, F = 7 m, G = 1 m.

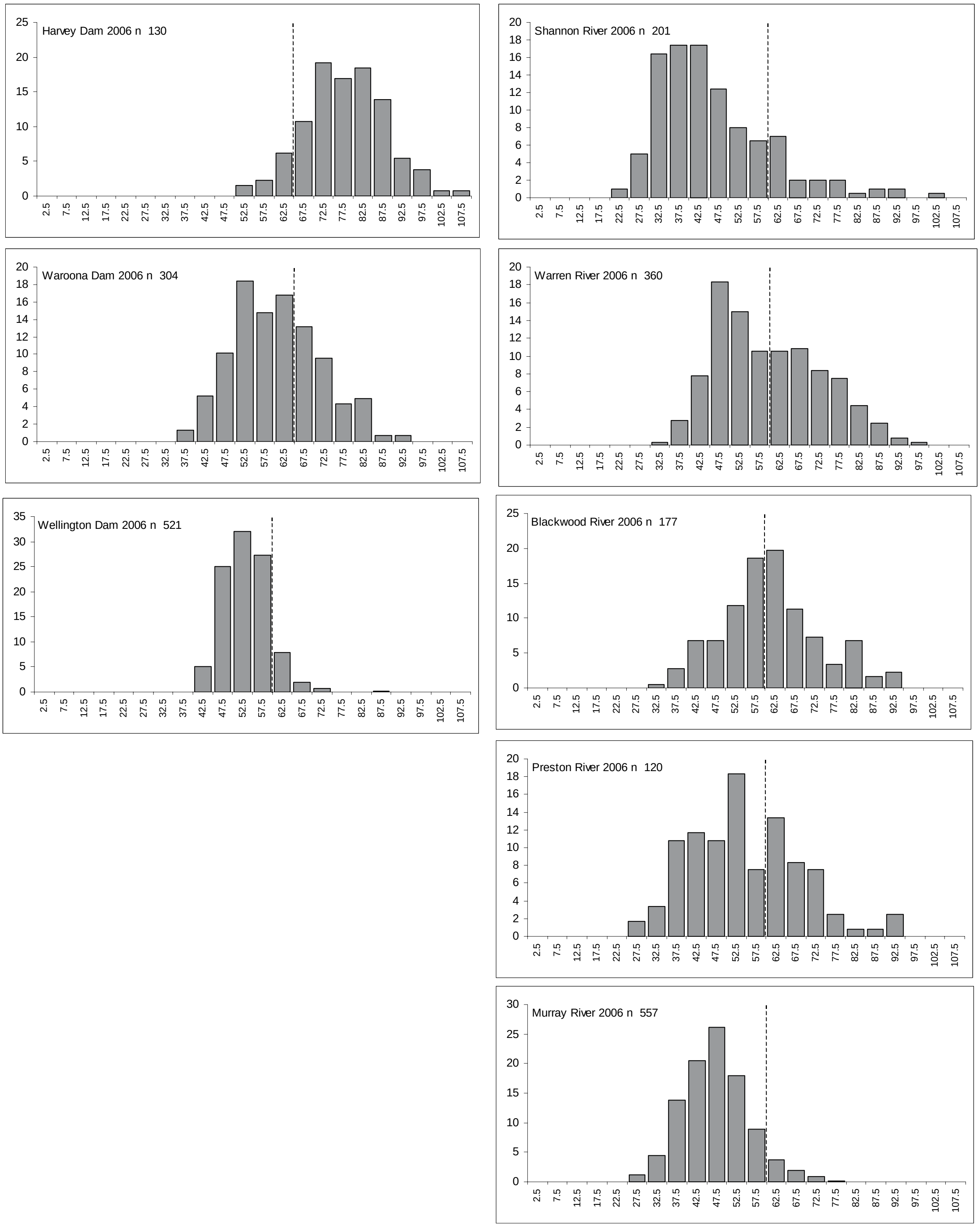
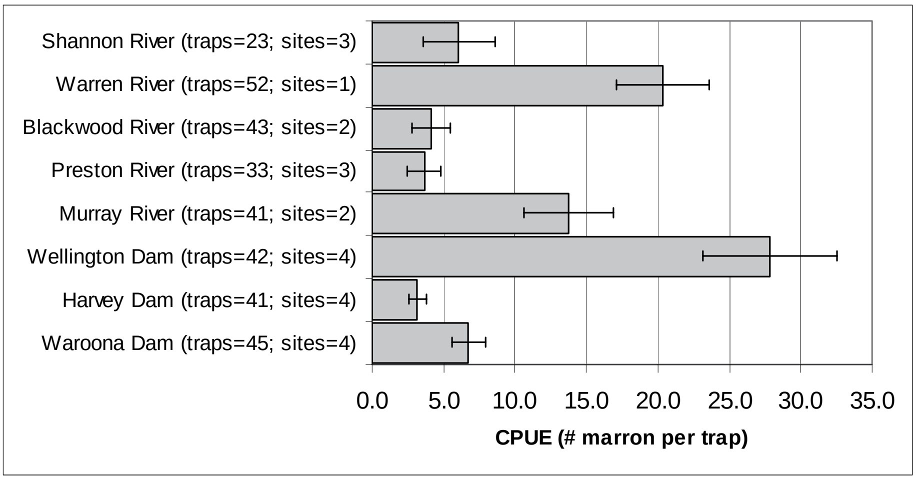


Figure 12. Comparison of length-frequency (mm OCL) distributions of *C. cainii* sampled with traps in dams and river in the southwest of WA during the annual survey in October/November 2006. Dotted line indicate legal size in each water body.

(a)



(b)

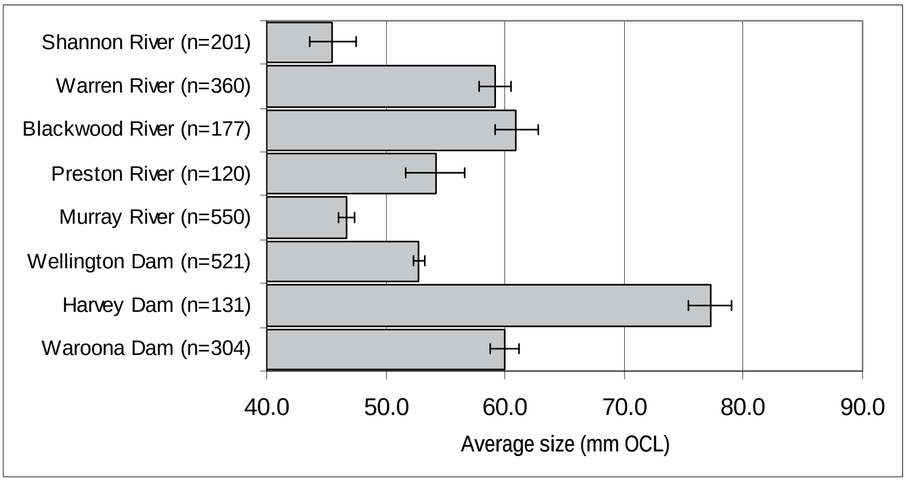


Figure 13. Comparison of average (a) CPUE and (b) size of *C. cainii* sampled with traps in dams and river in the southwest of WA during the annual survey in October/November 2006. Error bars indicate 95% confidence intervals.

8.0 Estimating abundance of juvenile marron, *Cherax cainii*, in dams and rivers in southwestern Australia

Martin de Graaf and Stephen Beatty

8.1 Introduction

An important achievement in research into the sustainable management of the Recreational Marron Fishery (RMF) would be the development of a reliable and objective method of determining (relative) abundance of juvenile (0+) marron. Juvenile abundance combined with growth and mortality data, would make it possible to predict future recruitment into the Recreational Marron Fishery. Such predictive models would greatly enhance the sustainable management of this fishery. For example, in the WA rock lobster fishery, puerulus collectors ('habitat trap's) are being used very successfully to determine the relative abundance of puerulus settlement, that is used to make reliable future (3-4 year in advance) predictions of commercial and recreational catches (Caputi et al. 1995, Melville-Smith et al. 2001).

Marron stock assessments have historically been conducted using baited drop nets in rivers and baits and scoop nets in dams (Molony and Bird 2002). Both methods are; (a) biased towards large (>30 mm orbital-carapace length [OCL]) (male) marron, (b) do not provide a clear estimate of density because they are not area-specific, and (c) do not target or retain juvenile marron. These methods are therefore unsuitable to obtain data on recruitment which in turn is required for future predictions of recreational marron catches.

A reasonable amount of attention has been given to the effects of different sampling methods (e.g. visual surveys, quadrat samplers, baited traps, hand nets, electrofishing) on estimates of freshwater crayfish population size distribution and densities in a variety of habitat such as rivers, lakes and wetlands (France et al. 1991, Lamontagne and Rasmussen 1993, Rabeni et al. 1997, DiStefano et al. 2003, Dorn et al. 2005, Chapter 7). Both habitat and sampling method strongly influence the composition (abundance, size and sex) of a sample. Overall, stratified sampling based on distinct habitat types using area-based (quadrat) methods provide the most reliable estimates of juvenile freshwater crayfish densities compared with scoop netting and passive methods like baited traps or drop nets.

The aim of the current study was to trial two methods, habitat traps and visual surveys, for their suitability for determining juvenile marron abundance in dams and rivers in the southwest of Western Australia.

8.2 Materials and Methods

Artificial habitat traps

In January 2006 (Warren River 17/1/2006, Wellington Dam 18/1/2006) 10-12 habitat traps of six different designs were placed parallel to the shore at regular intervals (~10 m) in shallow water (max. 1 m deep in Warren River, max. 4 m deep in Wellington Dam) at each of the two study sites. Six habitat trap designs were compared (Fig 2):

PLA = ~20 black plastic tubes (length 15 cm, diameter 12 mm) packed tightly together in a white plastic holder (length 15 cm, width 11 cm, height 6 cm), surface area (length x width) 165 cm^2 (designed by Brett Molony);

CAV = hollow brick (length 15 cm, width 30 cm, height cm) with 20 (length 15 cm, width 2 cm, height 2 cm) holes blocked on one site by fine (1 mm) mesh, surface area (length x width) 450 cm^2;

TUN = hollow brick (length 30 cm, width 15 cm, height 9 cm) with 12 (length 30 cm, width 2.5 cm, height 1.5 cm) holes, surface area (length x width) 450 cm^2;

MES = a folded piece of plastic black square mesh (0.5 mm bar mesh) attached to a length of rope (1-1.5 m), surface area (length x width) ~2500 cm^2;

MST = a folded piece of plastic black square mesh (0.5 mm bar mesh) attached to a length of rope (1-1.5 m), the rope was weighted on one site and had a float attached on the other site to achieve that the habitat to would stand straight in the water column in contrast with MES habitat trap which was positioned on the bottom, surface area (length x width) ~900 cm^2;

TAN = a series of 25 cm long tassels made from Tanikalon fibre attached to a 1 m long rope, surface area (length x width) ~2500 cm^2.

The abundance of juvenile marron was determined twice at each location during 2006, Warren River 28/2/2006 and 3/5/2006, Wellington Dam 20/2/2006 and 3/4/2006. On each occasion, a diver using a large circular scoop net removed the habitat traps from the bottom. On board a small sampling vessel the net and habitat traps were carefully searched for the presence of marron and other fauna. Juvenile marron were measured, sexed and returned to the water.

In a separate experiment habitat preference trials were conducted at the Pemberton Freshwater Research Centre, Department of Fisheries, WA. A juvenile marron was placed in the middle of a circular tank (diameter 1.7 m, water depth 0.3 m) with five different habitat traps (TAN, TUN, CAV, PLA and MES) of roughly equal (~400 cm^2) size. After 24 hours, the location of the juvenile marron was recorded. Habitat traps were randomly assigned to each of five positions in the tank before each trial and water flow through the tank was disconnected for the duration of each trial. In total 28 trials were run between 20/2/2006 and 24/4/2006.

Visual survey

In April 2007 the abundance of juvenile (<20 mm OCL) marron in Drakesbrook Dam was determined using 0.25 m^2 quadrats. The quadrats were placed on the bottom at ~10 m intervals parallel to shoreline in water less than 0.5 m deep. Both quadrats and the habitat traps were placed in shallow water because juvenile crayfish are more often confined to shallow areas with abundant shelters than adult crayfish (Englund and Krupa 2000). The contribution of the habitat categories within each quadrat was estimate to the nearest 10%. The following habitat categories were distinguished: Sand, Mud, Rock <5 cm, Rock 5-15 cm, Rock 15-50 cm, Rock >50 cm, Aquatic Vegetation and Wood. The abundance of juvenile marron in each quadrat was recorded.

8.3 Results and Discussion

Artificial habitat traps: size variation

The length-frequency distribution and average size of the juvenile marron collected from the habitat traps (pooled) at Wellington Dam and Warren River on the two sampling occasions are shown in Figure 3. Mean size of juveniles was significantly different between the four samples (ANOVA $F_{3,206}$=7.5, p<0.000). At both locations the average size of juvenile marron collected from the habitat traps was larger in the second sample (April-May) compared to the first (February). However, no spatial effect was observed, as mean size of the juveniles did not differ between Wellington Dam and the Warren River in both the February or April-May collections.

Average size of juvenile marron differed significantly among the six habitat traps (ANOVA $F_{5,204}$=11.9, p<0.000) (Fig. 4). The average size of juvenile marron collected from the CAV and TUN habitat traps was significantly larger then the other four styles (Fig. 4). The CAV and TUN attracted a wider range of juvenile marron, most likely a combination of 0+ (~5-10 mm OCL) and 1+ (~20 mm OCL) juveniles. Only 0+ juveniles were harvested from PLA, MES and MST habitat traps. The TAN traps collected predominantly 0+ and fewer 1+ juvenile marron.

Artificial habitat traps: CPUE

A significant effect of habitat trap type on CPUE was found on each sampling occasion (Fig. 5: Kruskal-Wallis a) $H_{5,55}$=12, P<0.035 b) $H_{5,57}$=17.6, P<0.0035, c) $H_{5,55}$=18.3, P<0.003 d) $H_{5,51}$=15.5, P<0.008), but the differences were small. Overall, the MES and MST habitat traps were the least effective, producing a low CPUE and high percentage of zero catches (Fig. 5). Most effective was the TAN habitat trap as demonstrated by the low percentage of zero catches and higher CPUE closely followed by the CAV, TUN and PLA habitat traps (Fig. 5).

However, the surface area (cm^2) of the TAN and MES habitat traps (~2500 cm^2) were considerably larger than the MST habitat trap (~900 cm^2), the TUN, CAV (450 cm^2) and especially the PLA habitat trap (165 cm^2). When CPUE was adjusted for surface area, the PLA habitat trap proved to be the most efficient design (Fig. 5e).

Artificial habitat traps: preference trials

On all but one of 28 trials, the juveniles selected and inhabited one of the five habitat traps. No significant difference in preference for any of the habitats was observed, although the experiment revealed a slight bias towards the TUN habitat trap (Fig. 6).

Visual survey

The results of the visual survey (0.25 m^2 quadrats) to determine juvenile marron abundance are presented in Figure 7 and Table 1. Environmental parameters did not differ among sites 1, 4 and 5 (Table 1). Habitat and juvenile marron densities were similar among sites 2, 3, 4, 5 and 6. These five sites were characterized by a high percentage cover of mud (70-100%) and low juvenile marron densities (<0.5 juveniles per 0.25 m^2). Site 1 was remarkably different, being the only site with a high percentage of rock cover (>70%) and significantly higher densities (5-10 times) of juvenile marron (Kruskal-Wallis $H_{5,86}$=40.1, P<0.0001).

Conclusions and future research

The results of both techniques (habitat traps and area-based visual surveys) are encouraging and suggest a need for further development and refinement of each method in 2007/2008 with a goal of initiating an annual marron recruitment monitoring program in 2008/2009.

The main advantage of the ‘habitat’ trap method over the ‘visual survey’ method is that it can be used in both rivers and dams and is less labour intensive. Among the different habitat traps the most promising design would be an improved and larger version of the PLA trap. The advantages of PLA traps over TAN, TUN and CAV traps are that plastic habitat traps are:

1) effective in retaining 0+ marron, 2) cheap to construct in large numbers, 3) light enough to transport in large numbers, and 4) remain light and clean after being left in the water for a prolonged period of time.

A limitation of the current PLA habitat trap design is its small size. The maximum number of juvenile marron harvested from a PLA habitat during this trial was only 3 juveniles compared to CAV (2), MES (4), TUN (5), TAN (6) and MST (8). The small size of the PLA habitat trap probably reduced encounter rates and limited the space available for juvenile marron to settle. Potential large temporal or spatial differences in juvenile marron densities will not be properly detected due to rapid saturation of the current small PLA habitat trap design.

In 2007/2008 modified PLA habitat traps will be constructed based on the ‘bag trap’ design of Blake & Hart (1993) and tested in Wellington Dam and Warren River. Blake and Hart (1993) showed that more than 50 juvenile *Pacifastacus leniusculus* could be harvested from an individual ‘bag trap’ placed for a week in a large pond (20,000 m^2; maximum depth 3 m). The modified PLA habitat traps will be constructed out of plastic net bags (50 x 25 cm, mesh size 10 x 10 mm), each filled with plastic cylinders (10 mm diameter, 5 cm long). At each location between 20 and 40 bag traps will be placed in shallow water (0.5-2 m) for a period of two weeks in February/March. Depending on the success of these trials, an annual 0+ marron monitoring program will be launched in 2008/2009 in the same 12 rivers and dams used for the annual stock assessment to develop a recruitment index for the Recreational Marron Fishery.

The visual survey method is mainly suitable for dams but does provide an estimate of absolute and not just relative abundance. Furthermore this method can be used to ‘truth’ the habitat trap method. The visual survey method clearly demonstrated the effect of high quality littoral substrate (rocks with high shelter potential) on juvenile marron densities in Drakesbrook Dam. Similar considerable habitat related differences in juvenile abundance such as, high abundance of juvenile freshwater crayfish on quality substrate (rock) and low abundance of juveniles on low quality substrate (mud), were observed for *Pacifastacus leniusculus* (Blake and Hart 1993) and *Oronectes virilis* (France et al. 1991) in lentic environments.

Aquatic vegetation is very limited in Drakesbrook Dam but when encountered resulted in difficulties in marron abundance estimates. Carefully removing the vegetation from the quadrat resulted in very poor visibility and most likely allowed juvenile marron to move out of the quadrat without being noticed by the observer. To prevent the escape of juvenile marron the design of the quadrats will need to be modified. Adding a fine mesh skirt and side panels would transform the quadrat effectively into a kind of small ‘throw trap’. Throw traps are a highly efficient method to collect freshwater crayfish in heavily vegetated areas (Dorn et al. 2005).

The adjusted PLA habitat trap and area-based visual survey methods should provide a reliable index of juvenile abundance and recruitment in the near future. The development of a stock prediction tool will significantly improve the management and sustainability of the iconic Recreational Marron Fishery.

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Table 1. Abiotic parameters measured at 0.5 m depth at Sites 1, 4 and 5 in Drakesbrook Dam on 20 April 2007.

	Temperature (°C)	Oxygen (%)	Oxygen (mg/l)	Conductivity (mS/cm)	pH	Secchi (m)
Site 1	19.4	83.7	7.7	0.27	8.7	1.9
Site 4	19.3	87	8	0.27	7.9	1.9
Site 5	19.4	85	7.8	0.27	8.2	1.9

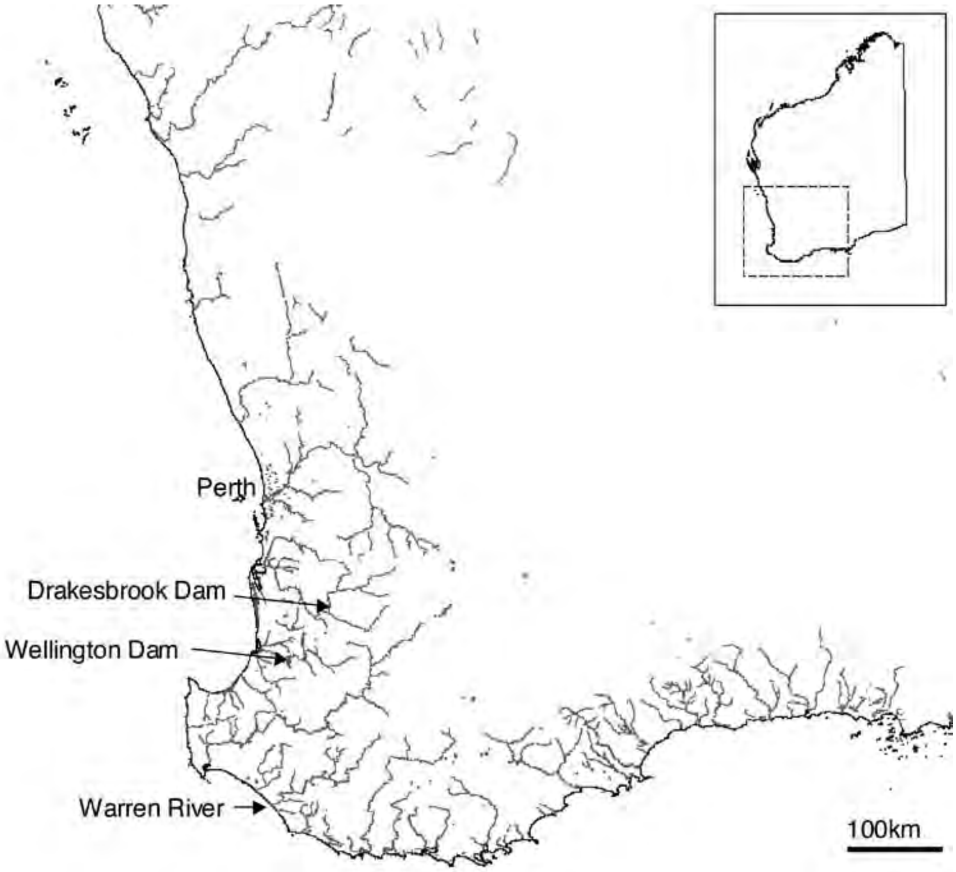

Figure 1. Location of study sites Drakesbrook Dam, Wellington Dam and Warren River in southwestern WA.

Figure 2. Different types of juvenile collectors used in Wellington Dam and Warren River. PLA = plastic cave, CAV = brick cave, TUN = brick tunnel, MES = onion mesh, TAN = Tanikalon fibre. Horizontal bars indicate 5 cm.

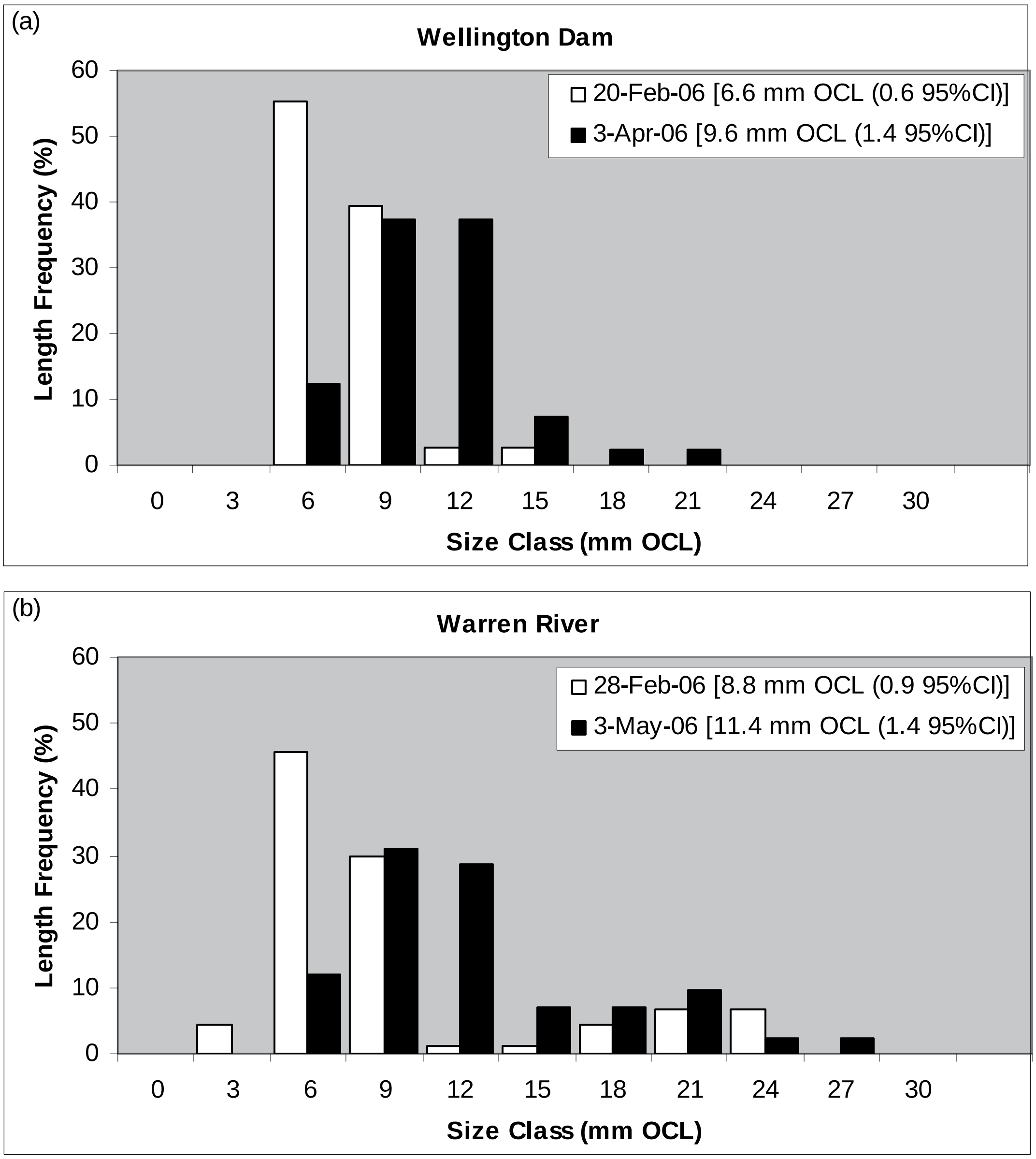

Figure 3. Pooled length-frequency distributions of juvenile marron from the six habitat traps in Wellington Dam (a) and Warren River (b).

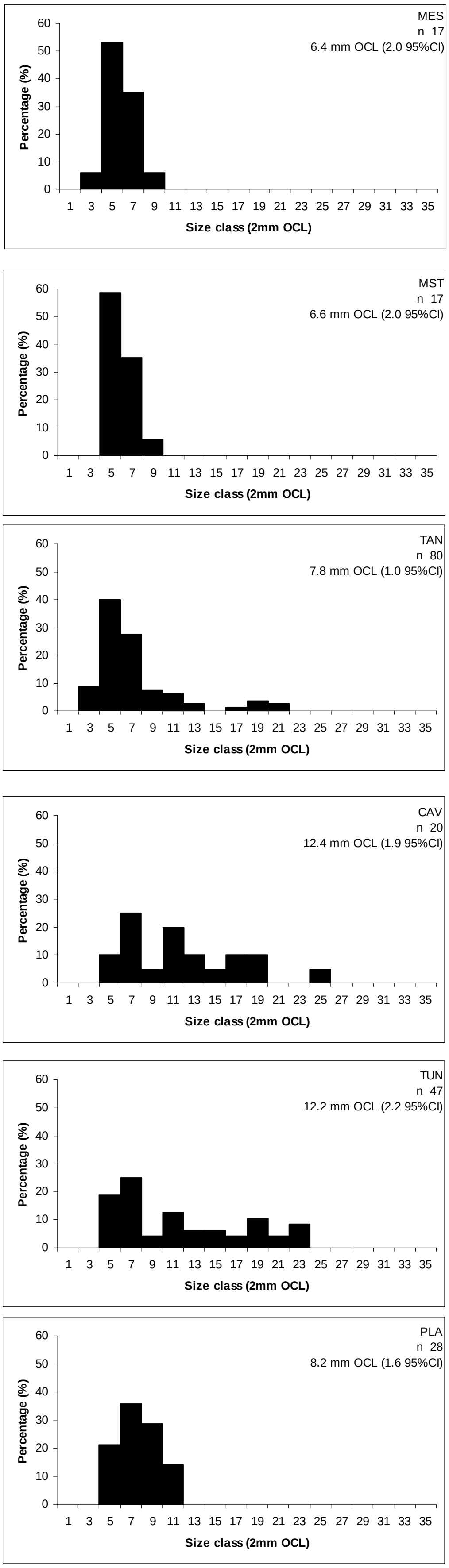

Figure 4. Length frequency distribution of juvenile marron collected in Wellington Dam and Warren River from the six different habitat traps.

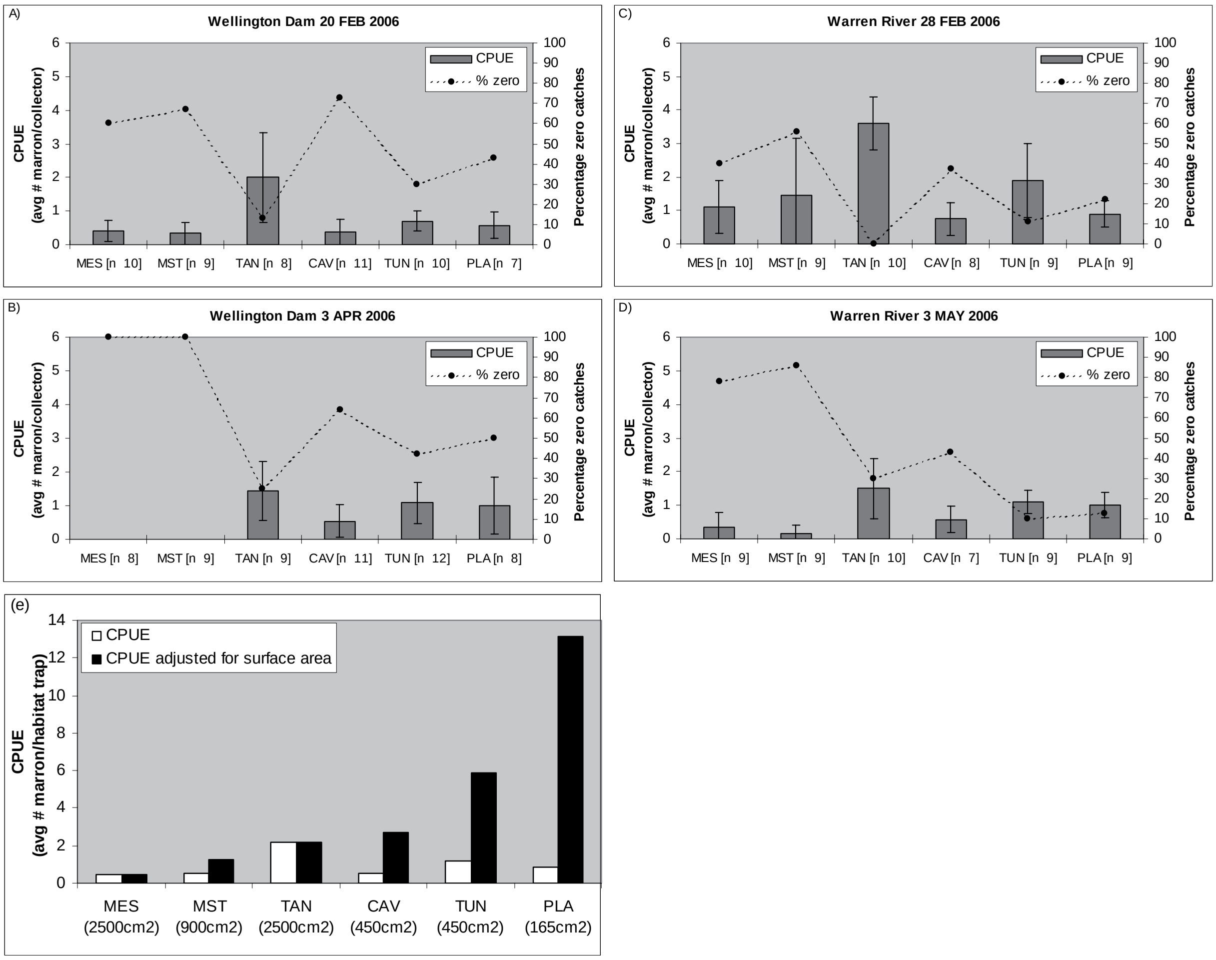

Figure 5. CPUE of the juvenile marron of the six different habitat traps (hide types) at Wellington Dam (a,b) and Warren River (c, d). Theoretical CPUE of the six habitat traps when adjusted for surface area (e).

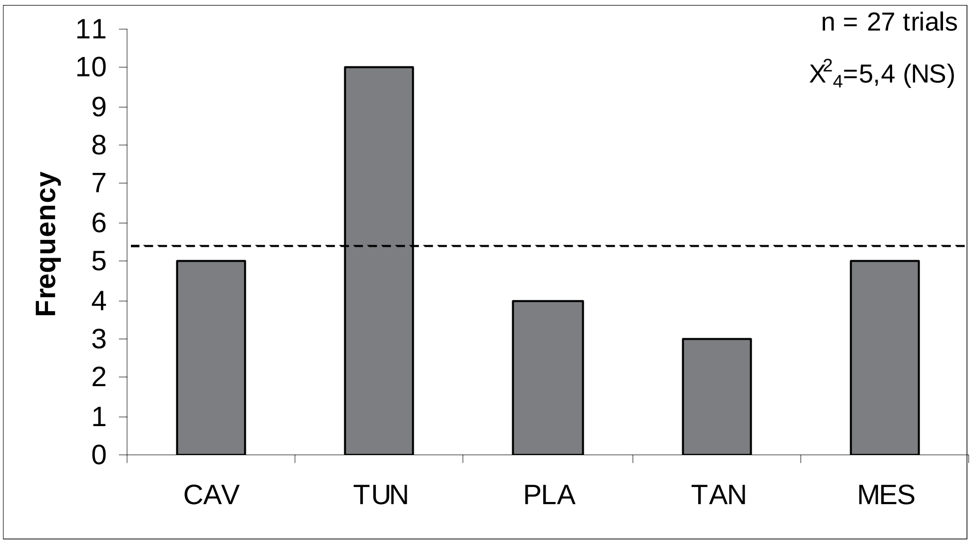

Figure 6. Habitat trap (hide type) selection of juvenile *C. cainii*.

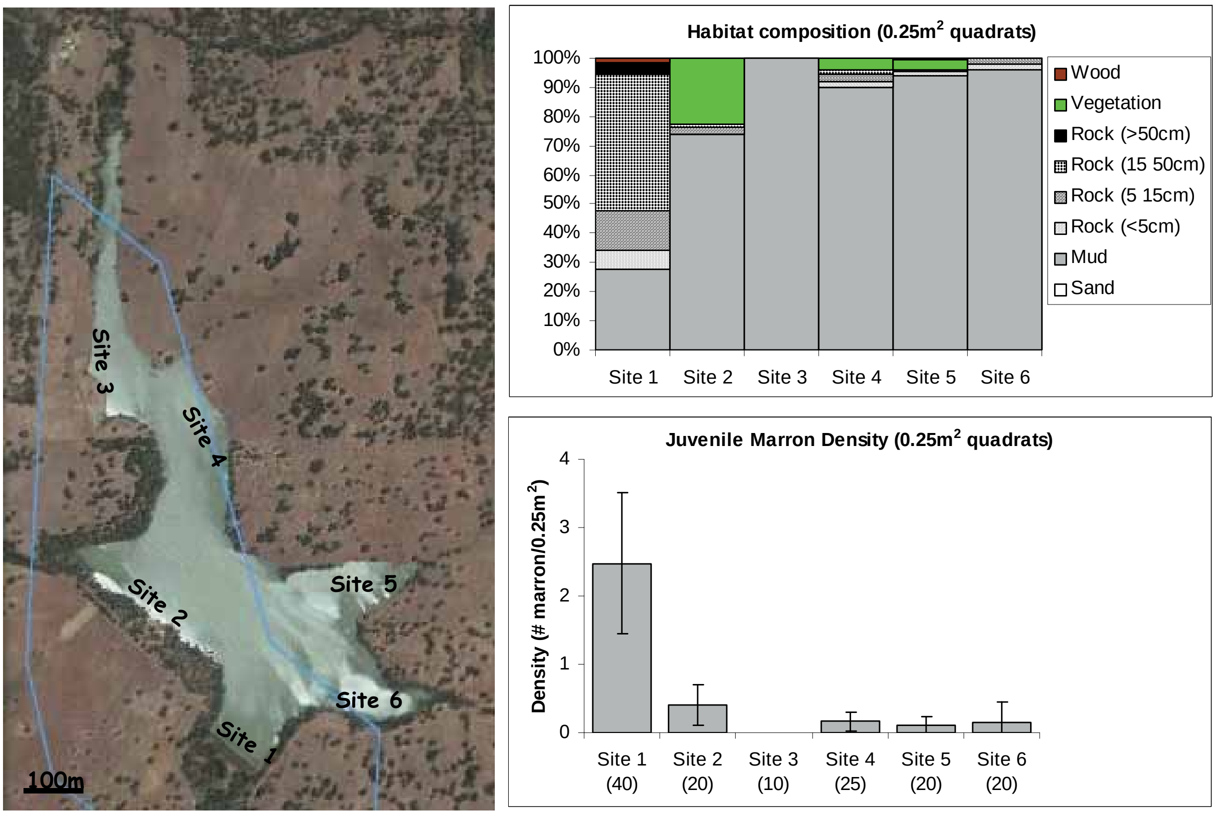

Figure 7. Location, habitat composition and juvenile marron density, recorded at six sampling sites in Drakesbrook Dam. Vertical bars indicate 95% confidence intervals.

9.0 Benefits and Adoption

The main beneficiaries of the research are the stakeholders in the marron resource, i.e. government managers, recreational fishermen and scientists. This project has enabled a thorough review of the recreational marron fishery as a whole and particularly the historical monitoring and sampling protocols. It has significantly enhanced the development of a range of new methodologies, which will provide more reliable, high quality fishery-independent data to assist in the sustainable management of this iconic fishery.

During the course of the project 8-10 key indicator sites were identified for fishery-independent sampling. Historical survey protocols where thoroughly reviewed (costs, occupational health and safety, sampler bias, data quality), resulting in 2006 in a new annual stock assessment program conducted at each of the indicator sites using inexpensive, easy to use black box traps. The highly biased fishery-dependent data that were historically used, are poor indicators of true stock abundance. The implementation of a simple and robust fishery-independent monitoring program will greatly improve the management of the fishery.

The project has provided the first overview of spatial and temporal variation in reproductive characteristics like fecundity and size-at-maturity. This basic information is crucial to prevent recruitment overfishing in any of the major water bodies within the recreational marron fishery.

The growth, productivity and mortality study, is the first comprehensive comparative biological study on *C. cainii.* The study found that marron stocks are most likely habitat limited and fishing mortality and subsequent rates of exploitation differed markedly between the two indicator stocks with levels being far greater in the habitat poor dam stock, relative to the reasonably pristine river stock. The predation by native and/or introduced predators (trout, redfin perch) recorded during the study could not be linked to having a significant impact on marron abundance. Future management attempts to improve productivity should focus on habitat conservation and enhancement.

The success of the use of micro-wire tags in juvenile marron, has provided a powerful tool for obtaining growth and survival estimates for this period of the life-history.

The project has provided the first successful attempts to quantify juvenile abundance. The encouraging results will assist in the development of a recruitment abundance index, which in combination with fishery-independent abundance data and environmental variables, could be used to predict future marron catches.

10.0 Further developments

The results of the study have clearly pointed out the crucial importance of the continuation of a simple, solid and robust fishery-independent monitoring program. An annual fishery independent stock assessment using inexpensive box traps will provide reliable data on key population biology parameters such as abundance, population structure and production that will add to the comprehensive data obtained on the two key indicator stocks in this study. Most importantly, these survey data can be used to measure the performance and impact of newly implemented management initiatives. This should involve the inclusion of sentinel stocks closed to recreational fishing to assess the effectiveness of management strategies and actions. Furthermore fishery-independent data are more useful than biased fishery-dependent CPUE data when developing predictive environmental models or a recruitment index linking juvenile abundance with future adult abundance.

The logbook program (1970) and phone survey (2000) should continue in the future as these programs provide high-quality fishery-dependent data. Although not suitable as a reliable measure for true stock abundance, these data provide an accurate estimate of the total annual catch, CPUE, size of retained marron and detailed information on temporal and spatial changes in fisher behaviour.

This study has indicated the need for the development of a non-destructive method to determine female reproductive status externally and being able to distinguish between immature females and mature, non-reproductive females is highly desirable. Coded qualitative characters (level of calcification, amount of hair and profile), describing the gonopore is the most promising method to determine female reproductive status.

Data on spatial variation in size-at-maturity will need to be expanded in the future to identify possible other marron populations like Harvey Dam and Hutt River, where female marron mature at sizes similar or larger than the current minimum legal size. Further sampling in 2007 of the Moore River, Blackwood River and Margaret River should clarify whether or not these rivers should be managed as ‘trophy waters’ to avoid recruitment overfishing.

The encouraging results of the habitat traps indicated the possibility of developing a recruitment index that would allow the prediction of future recreational catches. It would be recommended to construct ‘bag traps’ based on the design of Blake and Hart (1993) and to conduct additional experimental trials in representative rivers and dams.

Large-scale micro-wire tagging programs would be useful to conduct in the near future to determine for the first time the growth and survival of juvenile and adult marron in the field, at key and marginal sites.

Over the next few years it would also be recommended to continue detailed surveys of rivers in the southwest to obtain high quality, standardised base line distribution data to monitor future changes in marron range. In order to improve distribution and abundance data, the DoF should be the leading organisation, collecting and storing survey data from other governmental organisations and universities. DoF should encourage other researchers to use similar sampling methods (black box traps) to improve comparisons of spatial and temporal data.

11.0 Planned outcomes

In bold are the outcomes that were identified in section B6 of the original applications;

1. Overall, a more sustainable recreational marron fishery will emerge.

The review of the marron fishery, the development of a robust fishery-independent annual monitoring program, the documentation of baseline population characteristics (growth, production, fecundity, size-at-maturity) and the advances in methodologies will greatly enhance the future sustainable management of the Recreational Marron Fishery. The comprehensive population biology studies of the indicator stocks in the Wellington Dam and Warren River have provided valuable information that has direct implications for the sustainable management of the fishery. Most importantly, solid and reliable protocols are now in place to accurately monitor changes in both the Recreational Marron Fishery and the actual marron stocks.

2. Re-evaluation of the current extent of the recreational marron fishery.

The range of the Recreational Marron Fishery appears to have contracted within most catchments in the southwest, probably due to degradation of the riparian vegetation and a decline in water quality (salinisation). Furthermore, access to large public dams has declined over the last decade. In the near future, the Water Corporation has earmarked Wellington Dam as a possible future source of Perth's drinking water supply. Wellington Dam is by far the most popular marroning dam (~40% all dam effort) and the loss of this public dam would result in a significant reduction to range of the Recreational Marron Fishery.

3. Establishment of indicator sites for the future monitoring of the recreational marron fishery.

Several indicator sites have been selected for continued fishery-independent monitoring. The following locations Warren River, Blackwood River, Preston River, Murray River, Wellington Dam, Waroona Dam and Harvey Dam were selected because these sites receive >80% of the total effort. The Shannon River is one of the few rivers in the southwest with an almost completely uncleared catchment. Fishing in this 'sentinel' stock was banned in 2007. All of the above sites were sampled in 2006 as part of the new annual stock assessment for abundance, population structure and reproductive characteristics (fecundity, size at maturity). A comparable closed reservoir population should also be included in the ongoing annual monitoring program.

4. Ranking the impacts of different sources of mortality.

As part of the intensive stock assessment in the Wellington Dam and Warren River, key estimates of mortality (Z, F, M) were determined. Fishing mortality (F) was much greater in Wellington Dam (0.29year^{-1}) than Warren River (0.17year^{-1}) attributable to greater fisher access and a lack of hide habitat in the dam stock compared to the river. Similarly the proportion of total mortality attributable to fishing, (i.e. the exploitation rate (E)), of the Wellington Dam stock (0.62), was much greater than that of the Warren River stock (0.29). Natural mortality due to predation by turtles, water rats, birds and freshwater cobbler, had most likely a negligible effect on overall marron abundance. Marron contributed significantly to the diet of large, introduced piscivores (i.e. rainbow trout, brown trout and redfin perch). The impact of this predation on marron populations is apparently variable and dependent on the degree of habitat and relative densities. The highest marron densities were found in rivers and dams which had both trout species and redfin perch. Marron are only susceptible to predation during the juvenile stage (<30 mm OCL) and despite this predation on potential recruits to the fishery, these stocks remain sustainable. The critical resource bottle-neck is the availability of suitable shelter to protect against cannibalism and teleost predation, which are the major sources of mortality throughout their life.

5. Evaluation of the impact of changes in gear restrictions on historical catch and effort data available from the recreational marron fishery.

Traditionally 'raw' non-standardised fishery-dependent (logbook and phone survey) CPUE data have been used as an indicator of stock abundance or productivity. Standardising fishery-dependent CPUE data for one particular management initiative, the abolishment of scoop nets and the introduction of snares in the 1990s, clearly showed a significant bias in CPUE data. The effects of dozens of other management initiatives on historical fishery-dependent data remain to be quantified. These results stress the need for a fishery-independent monitoring program to determine stock abundance. Furthermore, is raises the question of how much of the decline in CPUE since the 1970s in the Recreational Marron Fishery is due to the actual decline of stocks and how much is the result of more than 50 years of management initiatives aimed directly at reducing CPUE of fishermen.

6. Development of productivity models of marron in indicators stocks, which will be applicable to other marron stocks, based on fecundity and recruitment.

It demonstrated that the Wellington Dam stock was effectively fully exploited and had very low productivity. The low density and apparent stunting of growth of larger individuals was attributed to a paucity of habitat and possibly food resources, and ease of fisher accessibility. By contrast, the Warren River stock had relatively low fishing exploitation and a high productivity driven by higher growth rates of trappable individuals coupled with higher densities. Increasing habitat diversity in Wellington Dam (and other fished dams) may result in increased densities and productivity of those stocks and that fishery effort could be sustainably increased in the Warren River (and other similar highly productive riverine marron stocks).

Reliable (ovarian and pleopodal) fecundity data were obtained for almost a dozen locations. However, despite successful pilot experiments, the methodology to estimate recruitment or juvenile abundance (visual surveys and bag traps) in rivers or dams needs to be further developed at this point before additional productivity models can be developed.

7. Development of stock performance measures by analysing and modelling historical data sets, adding value to previous research investments.

Unfortunately, limited modelling was achieved due to the lack of fishery-independent survey/research. Historical (1970s) data for making temporal comparisons were only available for the Wellington Dam (size-at-maturity) and Warren River (abundance, size-at-maturity, ovarian fecundity). However, the few historical fishery-independent data showed some important trends; 1) no temporal differences in size-at-maturity and fecundity, and 2) a possible increase in density and size of marron in the lower reaches of the Warren River since the 1970s.

8. Identification of the major environmental factors that influence the recreational marron fishery.

Environmental factors that influence the distribution of marron and hence the recreational marron fishery are 1) rainfall, river flow and dam fullness, 2) salinity, 3) degradation of the shoreline, riparian vegetation, shore erosion and 4) resultant decline of the quality and quantity of suitable habitat due to the previous factors.

9. Development of models of the influence of environmental variables on the productivity of the recreational marron fishery.

Modelling of environmental variables was only partially successful and resulted, at most, in indicative models instead of predictive models. Possible causes for the limited success are: 1) the marron data series were too short for proper time-series analysis, and 2) the use of biased fishery-dependent data as measures for recreational marron fishery productivity.

10. Identification of the major threats to the sustainability and productivity of the recreational marron fishery.

The decline in water quality and instream habitat complexity pose the greatest threat to the sustainability of the marron fishery. In addition, the reduction in the fishing access to public dams poses a threat to that component of the fishery. As dams are brought online for drinking water, all recreational activities, including all types of fishing, are banned. In the last few years Stirling Dam and Samson Dam were lost to the recreational marron fishery. At present discussions between the Water Corporation and stakeholders are determining the future of Logue Brook Dam. More threatening to the productivity of the Recreational Marron Fishery is the likely use of Wellington Dam, by far the most important marroning dam, as a source of drinking water in the next five to ten years.

11. Quantification of major variables influencing the recreational marron fishery but outside of the DoF's jurisdiction, to allow coordinated engagement of all natural resource managers to manage the recreational marron fishery and southwest inland bioregion sustainability with positive outcomes for the wider community.

Degradation of riparian vegetation, shore erosion and water quality (salinisation) have a negative impact on marron populations and require a co-ordinated approach with the Department of Water, the Department of Environment and Conservation and local catchments councils. At present, preliminary discussions have started between representatives of DoF, DoW and DEC to investigate options for future co-operation in the conservation and rehabilitation of freshwater habitats. Marron should be promoted as a iconic indicator species of river health in southwestern Australia.

The reduction in access to dams and sections of rivers when allocated as drinking water storing is a major threat to the marron fishery. Ongoing negotiations are being conducted to determine whether or not (limited) recreational fishing may be possible in drinking water dams. Furthermore, DoF and other stakeholders are negotiating with Water Corporation to identify possible options to offset the loss of fishing grounds by improving the quality and productivity of remaining water bodies (shore restoration, habitat enhancement).

12. An overall understanding of why the fishery has declined.

Based on the results of this project it is important to separate the temporal changes in the marron fishery from changes in marron distribution and abundance. Currently, marron are not a threatened species and many sustainable populations exist throughout its historical and translocated range. However, the decline of the natural inland marron range within catchments in the southwest is an indication of the general decline of water and habitat quality of these systems. In fact, the total marron range is larger, through seeding of river and dams, than their original distribution before European settlement. However, the decline in access to large public dams may have a negative impact on the Recreational Marron Fishery by reducing the amount of available fishing grounds; it actually creates significant protected refuges for marron.

Is the reduction in annual landings and CPUE due to a collapse of marron stocks or does it merely reflect the highly successful 50 years of management initiatives aimed directly at reducing total catch and CPUE? Standardising the fishery-dependent data for gear changes clearly demonstrated the bias introduced in CPUE data by just one management initiative. However, literally dozens of management changes have been introduced since the 1950s that impact total landings and CPUE and hence bias CPUE data as a measure for 'stock abundance'. Interestingly the few fishery-independent data that are available show an increase in CPUE and size in the Warren River, one of the most heavily fished rivers.

The overall recommendation is to promote the species as an iconic freshwater indicator species of riverine health and to continue to make resources available for ongoing fishery-independent monitoring. These actions should occur in addition to the current fishery-dependent surveys to record changes in marron stocks and to evaluate the performance of management initiatives.

12.0 Conclusions and Recommendations

The following objectives listed below (in bold) are those that were identified in section B4 of the original application;

1. To assess the present range of the Recreational Marron Fishery and compare to the historical range to quantify the reduction in marron range and current extent of the fishery.

The present distribution of marron in the southwest of Australia has seen many changes since European settlement. Reconstructions of their range from historical records suggest marron originally inhabited the waters between the Harvey River and Denmark River. Due to translocation, their range has expanded as far north as the Hutt River and as far east as Esperance. However, although marron still inhabit all the original pre-settlement rivers within the southwest, the distribution of populations within these rivers have contracted. Poor water quality, salinity, low rainfall and environmental degradation in the upper reaches have restricted marron to the relatively fresh (low salinity) lower reaches (young drainage) of each river system.

Recommendation(s)

- Conduct standardised surveys to determine distribution *and* abundance of marron in key rivers (~12), to be repeated every 5-10 years.
- Development of a spatial database by DoF for marron and other freshwater crayfish and finfish.
- Ongoing dialogue with universities and other governmental departments to standardise marron sampling gear and exchange data on marron distribution and abundance.
- Ongoing dialogue with all natural resource management agencies (Department of Water, Department of Environment and Conservation), in order to promote marron as a key indicator of river health and generate positive outcomes for the sustainable management of freshwater systems in Western Australia.
- The predicted future reduction in rainfall and river flow and the likely negative impacts on Marron populations needs to be considered when planning for the long-term sustainable management of the fishery.

2. To assess fecundity, recruitment and survival of marron in indicator sites to develop performance measures and models of productivity.

The relationship between female size and fecundity was conservative, with little spatial or temporal variation in both ovarian and pleopodal fecundity. Egg loss during spawning was high (~40%) and independent of female size. Size-at-maturity was highly variable among different populations ranging from ~30 to ~70 mm OCL. Furthermore, gonad analysis showed that some marron populations appeared to have significant numbers of mature but non-reproductive females, suggesting a trade-off between growth and reproduction.

It demonstrated that the Wellington Dam stock was effectively fully exploited and had very low productivity. Low productivity of in the system was driven by low densities (due to low habitat diversity and food resources) and an apparent stunting of growth of larger individuals. The high exploitation was probably due to the ease of fisher accessibility and low habitat diversity. The Warren River stock in a relatively pristine river section had a high productivity as a result of high growth rates of trappable individuals and higher densities. This was attributed to high degree of habitat complexity and probably food resources. The level of exploitation could be sustainably increased in this river.

Visual observations using scuba proved successful in determining juvenile densities but this method is costly and can only be used in dams. 'Habitat traps' provided encouraging results in both rivers and dams but the design needs further improvement and 'truthing' before it can be used as an index of recruitment.

Unfortunately, tail punctures were only visible for a few moults and could only be used reliably for large individuals (>40 mm OCL). Coded micro wire tags proved to be a potential tool to determine growth and survival of marron, including small juveniles, under natural conditions.

Overall, the advances in methodology and knowledge of marron biology here has made it significantly more likely that reliable productivity models can be developed in the intermediate future.

Recommendation(s)

- Implement large-scale CWT mark-recapture programs to determine growth and mortality of other wild stocks during the whole life history of marron including juvenile stage.
- The independent annual stock assessments should be related to annual recreational catches to validate its predictive power in determining future recruitment to the fishery and subsequent recreational catches.
- Development of a non-destructive methodology to determine female reproductive status externally using coded qualitative characters describing the gonopore development.
- Continuation of research surveys to determine spatial and temporal variation in size-at-maturity and fecundity.
- Development recruitment index; conduct further experiments using 'bag traps' and visual surveys to quantify marron juvenile abundance.

3. To quantify the relative efficiency of the three permitted capture methods at indicator sites and use the results to standardise the historical catch and effort database.

The catchability of the three legal gear-type used in the Recreational Marron Fishery was determined in dam and river sites by recreational anglers. Catchability varied among gear-types in rivers and dams. In rivers, drop-nets had the highest catchability, 60% higher than snares and triple that of scoop nets. In dams, scoop nets had the highest catchability per unit effort, approximately three-times greater than any other gear. Catchability data and proportional gear use by marroners in rivers and dams between 1990 and 2004 were used to standardise nominal catch rates. Standardisation for gear usage had little effect on nominal river CPUEs, likely a result of the stable proportional gear use by recreational fishers since 1990. In contrast, standardisation for gear usage reduced the nominal dam CPUEs by up to 27% in dams in the early to mid 1990s, after which standardisation had little impact on catch rates. This is likely a result of major changes in gear use recorded as dam sites were declared 'snare-only' during the 1990s and early 2000s, reducing catchability.

These results illustrated the limited use of fishery-dependent data (CPUE) as indices of true stock abundance. The fishery-dependent recreational marron fishery data are highly influenced by the numerous changes in management initiatives in the marron fishery, significantly biasing CPUE as a reliable index of abundance.

Recommendation(s)

- Continuation of fishery-dependent surveys to monitor changes in the fishery but implement fishery-independent research surveys as indices for true marron stock abundance.

4. Piloting the qualitative assessment of mortality sources of a selected marron population.

Fishing mortality was much greater in Wellington Dam than Warren River that was attributable to greater fisher access and a lack of hide habitat in the dam compared to the river. Similarly the proportion of total mortality attributable to fishing, (the exploitation rate) in the Wellington Dam stock was much greater than that of the Warren River stock. Although variable predation on juvenile marron by teleosts was found to occur, little evidence was found to support the hypothesis that marron stocks are (recruitment) limited due to predation of introduced fish like redfin perch and trout or any other predators like native birds, reptiles or marsupials. Marron were most susceptible to predation as juveniles (<30 mm OCL).

The reduction of the fishing season from 135 days in the 1970s and 1980s to 16 days in the early 2000s, reduced adult mortality by factor 10. Together with water quality (Chapter 1), the availability of (complex) habitat in both rivers (by maintaining riparian vegetation) and dams (by providing artificial habitat) are the most important factors in maintaining and increasing marron stocks and reducing mortality (predation and cannibalism).

Recommendation(s)

- Continuation of historical fishery-dependent surveys (log book since 1970; phone survey since 2000) to provide a reliable estimate of temporal and spatial variation in fishing mortality.
- Increase the understanding of the impacts of fishing mortality and management regulations through monitoring of other populations; including those that are fished and those sentinel stocks that are not subject to recreational fishing (e.g. Shannon River and large drinking water supply dams such as Mundaring and Serpentine).
- Continuation of research into the relationship between water quality, habitat quality and predators and marron mortality, distribution and abundance.
- Liaise with other agencies to protect river water quality and riparian zones as a crucial component of the long-term ecological sustainability of the Recreational Marron Fishery.
- Ongoing dialogue with Water Corporation to offset loss in fishing water (public dams) with projects that enhance water quality and habitat quality in rivers.

5. Piloting the identification of the impacts of major environmental variables affecting a selected marron population.

A possible reason for the lack of significant models could be the use of nominal fishery-dependent CPUE data from the logbook program. Fishery-dependent CPUE data are highly influenced by the numerous changes in management initiatives in the marron fishery, significantly biasing CPUE as a reliable index of abundance. Annual fishery-independent research surveys might prove more successful in the future to investigate the relationships between environmental variables like rainfall, water level and water flow and marron productivity to predict catches of the Recreational Marron Fishery.

Recommendation(s)

- Programs that protect or rehabilitate river water quality and riparian zones should be developed and promoted as a crucial component of the long-term ecological sustainability of the Recreational Marron Fishery.
- The importance of freshwater inputs, both surface and groundwater, for the long-term sustainability of marron populations should be recognised during water management allocation decisions.

- Marron should be promoted as a Western Australian faunal icon and used as a key indicator species of river health in southwestern Australia.
- Continuation of fisheries-independent research surveys to monitor changes in marron stocks.

Future of the Recreational Marron Fishery

The remaining marron populations, such as that of the Warren River indicator stock, currently appear not yet threatened with extinction and can continue to be fished sustainably. However, the decline of the natural inland marron range within catchments in the southwest is an indication of the general decline of water and habitat quality of these systems. The Recreational Marron Fishery will continue to be sustainable provided that the remaining freshwater habitats in which it occurs do not significantly decline as has occurred in the upper reaches of many of the rivers. It is of crucial importance for interagency cooperation in conserving the unique aquatic ecosystems and DoF should promote marron as a key, iconic indicator species of river health.

In future, marron fishing should be promoted as a fun and exciting activity that can be enjoyed with friends or family. Unlike many other recreational fisheries, the chances of catching a feed of marron during a fishing trip are still high and the costs to participate in the fishery are low. An important question is what defines an enjoyable fishery for the average recreational fishermen; retaining many marron in a few fishing trips or being able to go on regular marron trips throughout a prolonged season but retaining fewer animals. Currently, the marron season is short 16 to 23 days and prevents a lot of potential marroners from actually having on opportunity to go out and organise a fishing trip. From the analysis of the Warren River population, fishing exploitation in such a relatively undisturbed river section appears to be low and as such allowing some increased effort would be sustainable.

A viable option to prolong the marron season could be to promote the whole fishery as a high quality, snare-only Trophy Fishery with uniform conservative minimum legal size and conservative bag and possession limits. Such a straightforward approach would greatly simplify compliance, management and research. The fishery may be managed through a Total Allowable Catch (TAC). TAC can be adjusted by simply extending or decreasing season length based on marron stock development obtained from fishery independent data.

Such a snare-only, recreational marron ‘Trophy Fishery’ would allow for a significant increase in season length. This way more people will be able to participate and/or organise multiple marroning trips, providing an important economic advantage for rural communities.

13.0 Appendices

Appendix 1. Intellectual Property

There is no identifiable intellectual property arising from the project.

Appendix 2. Papers Produced

Tag retention, survival and growth of marron *Cherax cainii* (Crustacea: Decapoda) marked with coded micro wire tags.

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Martin de Graaf

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Introduction

Mark-recapture programs have been widely used in fisheries and ecological research to obtain quantitative estimates of an organism's fundamental biology such as mortality, growth, population size, age-at-maturity and movement. However, when working with crustaceans, ecdysis makes basic mark-recapture studies especially challenging as markings and tags fixed to the exoskeleton are lost during moulting (Davis 1978, Rowe and Haedrich 2001, McPherson 2002).

In marine crustacean research, external tags (e.g. T-bar tags, streamer tags) that either pierce the exoskeleton and are anchored in the underlying muscle tissue or are attached to the dorsal musculature between the cephalothorax and abdomen, are widely used to collect basic biological data. However, the validity of data obtained using these external tags may be in some cases questionable as, 1) tag loss can still be high during moulting, 2) recapture rates are dependent on factors like tag location, tag size and the application of antibiotic treatments and 3) tissue damage caused by external tags can affect growth, mortality and reproduction (Davis 1978, Forcucci et al. 1994, Montgomery and Brett 1996, Courtney et al. 2001, Rowe and Haedrich 2001, McPherson 2002). Melville-Smith and Chubb (1997) showed that lobster density and tag location (ventral or dorsal) had significant effects on the amount of T-bar tag damage and loss due to gnawing of the tags by other lobsters.

Another drawback of these external tags is that they are too large to be used on small (<50 mm carapace length [CL]) individuals like juveniles or small crustacean species. Several small tags like Visual Implant Elastomer (VIE; Woods and James 2003), VI Alpha tag (Isely and Stockett 2001) and Coded Wire Tag (CWT; Isely and Eversole 1998) have been trialled on small crustaceans. The CWT was introduced by Jefferts et al. (1963) and after being used initially in finfish, CWTs have been applied successfully in juvenile crustacean mark-recapture programs (Sharp et al. 2000, Webb and Kneib 2004). A 200-day laboratory study by Isely and Eversole (1998) using small (~15 mm CL) red swamp crayfish (*Procambarus clarkii*) showed high (100%) tag retention of CWTs and no effects on mortality and growth.

No large-scale and/or long-term field-based tagging studies have been conducted using freshwater crustaceans, probably due to the small amount of (commercial) freshwater crustacean fisheries compared to the many highly valuable marine lobster, crab and prawn fisheries. However, *Cherax cainii,* the third largest (up to 2 kg) freshwater crayfish species, supports a large strictly recreational fishery (20,075 license holders in 2005, de Graaf 2006). Despite the importance and vulnerability of the species and the recreational fishery in the southwest of Western Australia, basic biological field data on growth, mortality, age-at-maturity, fecundity and maximum lifespan are surprisingly scarce. Estimates of marron growth (Morrissy 1970, Beatty *et al.* 2004) using length-frequency data have to be interpreted with caution because successfully determining age-classes from length-frequency data is highly dependent on sampling size, sampling area and sampling gear (France *et al.* 1991). Furthermore, growth rate is highly variable between individual marron of the same age (Morrissy 1979), resulting in multiple overlapping age-classes.

The aim of this study was to explore the suitability of internal tags (CWTs) for future long-term tag-recapture programs to examine the population biology of marron in the southwest of WA. In this paper I discuss tag retention and the effects of tagging on growth and survival.

Materials and Methods

Juvenile *C. cainii* were obtained from the Aquaculture and Native Fish Breeding Laboratory at the University of Western Australia on 7 June 2006. Ten groups of 10 juvenile marron were marked with standard length (0.25 mm x 1 mm) coded-wire tags (CWT) using a Handheld Multishot Tag Injector (Northwest Marine Technologies, Shaw Island, Washington, http://www.nmt.us), which were injected into the muscle tissue of the first or second abdominal segment (following Isely and Eversole 1998, Kneib and Huggler 2001). After injection animals were scanned using a Handheld Wand Detector (Northwest Marine Technologies, Shaw Island, Washington) to ensure the tags were inserted.

Ten groups of 10 juvenile marron were not tagged and were used as controls. Each group was placed in a 100-L tank. Marron were fed commercial pellets (Glen Forrest Stockfeeders, Glenn Forrest, Western Australia, Australia) ad libitum. All tanks were part of the same recirculated system, flow rate in each tank was ~60 L/hr, photoperiod (light:dark) was 12:12, and water temperature ranged between 10.8 and 15.9 ^{o}C (average 13.8 ^{o}C).

On 30 August 2006 (day 54) the marron were checked for mortality and tag retention and were measured (to the nearest 1 mm Orbital Carapace Length [OCL]) and weighed (to the nearest 0.1 g body weight) before being translocated to the laboratory facilities at Western Australia Fisheries and Marine Research Laboratories (WAFMRL). Tagged marron that had lost their CWT during the initial 54-day period were removed at this stage. The remaining tagged and control marron were divided in 5 groups of 15 untagged marron and 4 groups of 15 tagged marron. Each group was placed in a 300-L tank. All tanks were part of an open system, flow rate in each tank was ~50 L/hr, photoperiod (light:dark) was 12:12, and water temperature ranged between 18.4 and 23.5 ^{o}C (average 21 ^{o}C). Marron were fed commercial pellets ad libitum. Mortality, tag retention and growth were subsequently determined on day 181, day 247, day 301, day 338 and day 394. T-tests were used to compare length (mm OCL) and weight (g) between the tagged and control groups at day 54, day 247 and at day 394. The interaction between changes in sample size (mortality), effect size and power was explored using power analysis. Differences in mortality between the tagged and control groups (day 1-54 and day 54-394) were compared using χ^2 analysis.

Results and Discussion

Tag retention after 54 days was 88% (Fig. 1a), with no further tag loss during the remainder of the trial (day 54-394). Tag retention rates were similar to values reported by other CWT tagging studies using juvenile crustaceans (juvenile lobster, *Hommarus gammarus* 85-100% Wickens et al. 1986; juvenile blue crabs, *Callinectes sapidus* 88%, Van Montfrans et al. 1986; juvenile red swamp crayfish, *Procambarus clarkii* 100%, Isely and Eversole 1998; juvenile Caribbean spiny lobster, *Panulirus argus* 86-96%, Sharp et al. 2000). Tag loss in juvenile marron appeared to be confined to the first post-tag molt similar to the findings of Van Montfrans et al. (1986), Fitz and Wiegart (1991) and Sharp et al. (2000).

Mortality was not significantly different between the CWT and control group during the first period (day 1-54: Yates corrected $\chi^2_{0.05,\,1}$ = 0.00, *P*=0.99 [day 1-54]. Figure 1a shows the cumulative mortality in the CWT and control groups during the second period (day 54-394). Although mortality was high (~80%) no significant differences (Yates corrected $\chi^2_{0.05,\,1}$ = 0.46, *P*=0.50) were observed between both groups. High mortalities are common when crayfish are held at high densities (60-93% mortality Jones 1981; 75-91% mortality, Isely and Eversole 1998) most likely due to cannibalism, despite the presence of shelter.

Average length (mm OCL) and weight (g) between control and tagged marron did not differ significantly (Fig. 1b,c) at day 54 (length; t-value=1.75, df=133, *P*=0.08, power to detect 5% difference between means was 0.99: weight; t-value=1.49, df=133, *P*=0.14, power to detect 10% difference between means was 0.91), day 247 (length; t-value=1.43, df=66, *P*=0.16, power to detect 5% difference between means was 0.83: weight; t-value=0.76, df=66, *P*=0.45, power to detect 20% difference between means was 0.87) and at day 394 (length; t-value=-0.22, df=30, *P*=0.82, power to detect 10% difference between means was 0.90: weight; t-value=-0.34, df=30, *P*=0.74, power to detect 25% difference between means was 0.81). Between day 54 and day 394 control and tagged juvenile marron increased markedly in length (~12.5 mm OCL; ~65%) and weight (~22 g; ~350%). Marking small (<20 mm OCL), juvenile marron with CWTs had no significant effects on survival and growth.

CWTs are widely used for large-scale finfish stock identification (especially salmonids; Johnson 1990) and other finfish mark-recapture studies (Brennan et al. 2007 and references therein) due to its negligible effect on growth and survival. Although fewer studies evaluating the use of CWT in crustacean biology have been conducted, the results of this and other studies using small crustaceans (e.g. Fitz and Wiegart 1991; Isely and Eversole 1998, Sharp et al. 2000) are promising. CWTs appear to be a reliable and effective way to determine biological parameters (growth, survival, migration etc) for small species (Webb and Kneib 2004) and/or early life stages (Sharp et al. 2000) that were previously unobtainable.

A major advancement in marron research that could be achieved with CWTs would be obtaining growth and survival estimates under natural conditions during the early juvenile stage all the way through to the adult stage. Furthermore, in the near future CWT mark-recapture programs could provide information on the efficiency of restocking programs in the re-establishment of marron stocks in refurbished and drained public dams.

Overall, CWTs appear to be a potential useful tool in quantifying aspects of juvenile crustacean biology. Increased information on the life-history of commercially and/or recreationally harvested crustaceans will be helpful to resource managers when making management recommendations.

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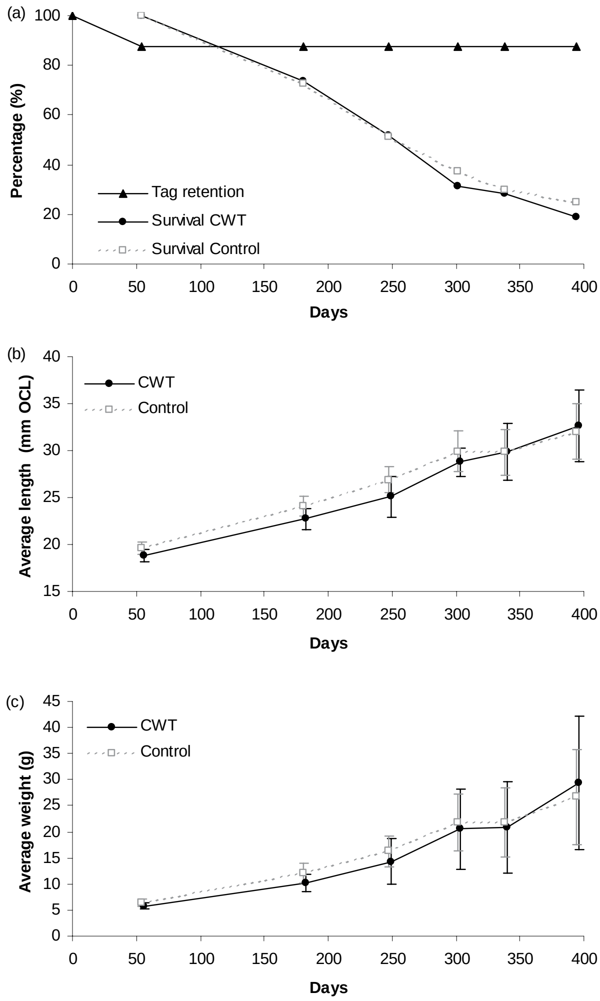

Figure 1. (a) Tag retention and survival, (b) growth in mm OCL and (c) growth in g body weight of CWT marked and control *C. cainii***.** Bars indicate 95% confidence intervals.

Appendix 3. Staff

Dr Martin de Graaf	Principal Investigator*
Dr Brett Molony	Principal Investigator*
Dr Stephen Beatty	Co-investigator*
Dr Iain Wright	Statistical Officer*
Mr Cameron Hugh	Technical Officer*
Mr Vinh Nguyen	Technical Officer**
Mr Chris Bird	Technical Officer#

* Staff employed for parts of the project under FRDC funding

** Staff employed fulltime under FRDC funding

\# Trained staff who assisted with the project using non-FRDC funds

The Western Australian Fisheries and Marine Research Laboratories
at Hillarys Boat Harbour, Perth, are the
centre for fisheries research in Western Australia