Breeding
Bigger
Yabbies

Developing a genetically improved yabby to facilitate farm enterprise diversification

A report for the Rural Industries Research and Development Corporation

By Dr Ian W Purvis

April 2006

RIRDC Publication No 06/042
RIRDC Project No CSA-17A
Breeding Bigger Yabbies - Developing a genetically improved yabby to facilitate farm enterprise diversification
Publication No. 06/042
Project No. CSA-17A

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Published in April 2006
Printed on environmentally friendly paper by Canprint
Foreword

Found throughout the country, yabbies are Australia's most abundant native freshwater crayfish. They are tough and can tolerate a wide range of environmental conditions. This makes them ideal for farm based aquaculture.

The objective of the research was to develop an improved strain of yabby with superior growth rate and higher tail meat yield than existing wild caught strains. The outcome will be an improved strain of yabby, which could be used to improve productivity, product quality and sustainability in commercial yabby production enterprises.

This project was funded from RIRDC Core Funds which are provided by the Australian Government.

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Peter O’Brien
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Dr Purvis is involved in research into gene mapping and selection using molecular tools, using the skills for gene mapping research he gained while working at the Roslin Institute in Scotland.
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Executive Summary

Water Management – A valuable commodity for Australian agriculture
The recognition that single-use systems of water management cannot be sustained when there is a continued requirement for an expansion of food production on a global basis, has been a key factor in generating increased interest from governments and the commercial sector toward the integration of aquaculture and irrigated livestock production and crop cultivation. A critical resource on most Australian livestock and irrigation enterprises is the collection of farm dams and water containment structures. Notions that single-use water strategies are inefficient and outmoded are becoming more and more prevalent with today’s farmer and will mean that Australia will see an increasing trend towards water management being valued on a commercial basis.

Enterprise Diversification
Agricultural producers wishing to explore aquaculture as a diverse enterprise, are presented with an opportunity to become more productive and profitable into the future whilst developing farming systems that will enhance the long term benefits of agricultural lands for landholders and their communities. Aquaculture will improve the efficiency of water utilisation on the farm by doubling the use of water, develop improved productivity and nutrient usage and provide assistance with reducing the risk of extreme fluctuations in farm income.

Background
With approximately one hundred freshwater crayfish species found throughout the country, yabbies are Australia’s most abundant native freshwater crayfish. Of these hundred or so species, three are now farmed in a considerable way. In Western Australia and parts of South Australia, marron (Cherax tenuimimus), which are native to the southwest of Western Australia, are farmed in purpose built ponds. Redclaw (Cherax quadricarinatus) are similarly farmed under controlled conditions on the coastal areas of Queensland and to a small extent on the northern NSW coast.

However, the majority of crayfish production currently comes from the yabby (Cherax destructor), which is farmed through NSW, VIC, SA and WA. Although there is enormous variability among wild strains of yabbies and some are more suited to commercial aquaculture than others, they are ideal for farm-based aquaculture.

Primarily omnivorous and an opportunistic feeder, the yabby will feed mainly on rotting vegetation. Muddy waterways provide protection from predators such as cormorants, herons, ibises and larger fish and invertebrates. Yabbies are tough and can tolerate a wide range of environmental conditions such as poor water quality and differences in water temperatures as low as 1 °C and as high as 35 °C.

Yabbies have been commercially farmed in Australia for over 30 years. However, in this time, there has been no attempt to improve the productivity of commercial stocks through scientifically based selective breeding programs. Growers simply source broodstock from local waterways or from other farms.

In 1999, one kilogram of yabbies could earn a farmer around $6 a kilogram. A bigger, faster growing yabby could increase profit margins considerably. With an ever-increasing interest in yabbies coming from the restaurant trade, an established aquaculture industry able to deliver a constant supply of high quality product to the market could be extremely profitable.

Aims of the Research
The objective of the research was to establish the best wild strains for aquaculture by discovering the heritability of desired characteristics, such as fast growth and large meaty tails. These strains were then selectively bred to develop a strain of yabby better suited to aquaculture.
Once such a yabby exists in an aquaculture environment, the yabby farmer can better control growth and quality of the livestock, important factors to maintaining a reliable and continuing market for this product.

Methods Used
Superior performing broodstock yabbies, from various geographic populations, identified by a strain comparison trial were combined to create a new “commercial” strain and subjected to four generations of within family selection. Faster growth was the primary selection goal. At the beginning of the trial the program was based on the evaluation of 100 full siblings from each of 30 families. Poor survival of three families reduced the total number in the program to 27. A control line consisting of randomly bred individuals from the 30 families was also maintained to allow assessments of genetic gain to be made through selective breeding.

Results
Of the four generations of selection, significant differences in mean liveweight at harvest were observed between select and control lines. The difference represented an average response to selection in both sexes of 12% per generation and a realized heritability for liveweight of 30%.

These results demonstrate that response to selection for liveweight in the yabby, *Cherax destructor*, can be successfully achieved. By selecting within families, significant gains were achieved in generations F2 and F3 that averaged around 15%. Coupled with the initial gains achieved by selecting the F1 founder generation, the select animals in generation F3 grew at 60-70 % faster than the average of all strains taken from the wild to initiate this study.
1. Introduction

Whilst there have been many optimistic reports about the potential for growth of Australia’s freshwater crayfish industry, a more objective examination of the production statistics show slow growth (Piper, 2000). Table 1 from that report, details the production levels in the latter part of the 1990s for the three major freshwater crayfish species: marron (*Cherax tenuimanus*); redclaw (*Cherax quadricanatus*) and yabby (*Cherax destructor*).

<table>
<thead>
<tr>
<th></th>
<th>96/97</th>
<th>96/97</th>
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<tr>
<td><strong>Species</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Marron</td>
<td>52</td>
<td>1274</td>
<td>48</td>
<td>1169</td>
<td>49</td>
<td>1187</td>
</tr>
<tr>
<td>Redclaw</td>
<td>65</td>
<td>876</td>
<td>62</td>
<td>833</td>
<td>61</td>
<td>875</td>
</tr>
<tr>
<td>Yabby**</td>
<td>288</td>
<td>2625</td>
<td>343</td>
<td>3261</td>
<td>296</td>
<td>2803</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>405</td>
<td>4775</td>
<td>453</td>
<td>5263</td>
<td>406</td>
<td>4865</td>
</tr>
</tbody>
</table>

* Source ABARE and State Fisheries;  ** Includes estimated production from wild catch

Piper (2000) concluded that opportunities for expansion of the freshwater crayfish industry were closely related to licencing and development laws within the states, lack of funds for R&D and inability of the embryonic industry to attract major investment due to the perceived low and inconsistent productivity and profitability.

It was against this industry background that CSIRO initiated an R&D project in 1998 focussed on the genetic improvement of *Cherax destructor* for more predictable and profitable aquaculture production.

The yabby, *Cherax destructor*, is a freshwater crayfish species indigenous to south-eastern Australia. Relative to marron and redclaw, yabbies grow faster, are tolerant of a wide range of environmental conditions and are easy to rear in farm dams. Because of these attributes, a small aquaculture industry developed in Australia with around 300 tonnes of yabbies produced in 2000. The stocks on which this production was based came from harvesting adult animals from the rivers and streams in their natural habitat. Natural breeding was the basis of increasing yabby numbers in farm dams, with very little attempts at selective breeding.

In 1998 CSIRO in Armidale initiated a project aimed at developing a strain of yabbies that through selective breeding was faster growing and more suited to aquaculture. The stimulus for this project came from the demonstrable success of domestication and selective breeding programs in other marine species (e.g. Atlantic salmon and rainbow trout (Gjerde 1986), and channel catfish (Dunham 1987). Breeding programs within Australia in redclaw crayfish and Kumara prawns have also been started (Jones, McPhee & Ruscoe 2000, and Hetzel, Crocos, Davis, Moore & Preston 2000). The key features of all these species were the presence of substantial genetic variation and high fecundity allowing high selection intensities, leading to relatively rapid genetic gain when compared to the experience in terrestrial livestock species. This was particularly true for traits such as growth rate and age at maturation where responses to selection of around 10% per generation had been observed (Gjedrem 1983).

The decision was thus made by CSIRO to evaluate whether a selective breeding program was likely to be successful by establishing the extent of genetic variation existing within and between a sub-population of yabbies across its natural geographic distribution. The objective was to sample across the spread of key geographic and ecological differences.
The results of this trial are fully described in Jerry et al (2002). The key features of the trial were that five geographically isolated populations were evaluated for the traits: weight at age, abdomen length and abdomen width over a period of nine months. Mean weight at age was found to vary between the populations by up to 42%, while mean abdomen length was similar among four of the five populations. No differences were found in abdomen width.

Yabby (*Cherax destructor*) breeding stock were collected from five locations: Population 1 – Wimmera River, Victoria; Population 2 – Warrego River, Qld; Population 3 – Tumut River, NSW; Population 4, Gywdir River, NSW; Population 5, Mooki River, NSW, and a trial was undertaken at CSIRO to establish genetic differences in growth among the wild populations.

As a result of this trial CSIRO together with RIRDC endeavoured to use this knowledge of genetic variability within and between strains of *Cherax destructor* to initiate a breeding program to produce a strain specifically suited to commercial aquaculture production.

1.2. Project Objective

The objective was to develop a genetically improved strain of yabby with superior growth rate and higher tail-meat yield than existing wild caught strains, which are the basis of commercial yabby production.

The outcome will be a genetically improved strain of yabby, which can be used to improve productivity, product quality and sustainability in commercial yabby production enterprises.
2. Methodology

2.1 Foundation population

The foundation broodstock for the selective breeding program were chosen from the Warrego and Tumut Rivers strains: these being the two most productive strains. A diallel cross of males and females from these two strains was chosen as the method that would capture the maximum genetic variability in the foundation population. Thirty hybrid full-sib families were generated from a total pool of 102 males and 204 females from these two strains.

Each male was mated with four females that were identified to be not in pre-moult. Once females were identified to be carrying eggs (berried) they were carefully transferred to individual aquaria. They were maintained in this way until the juveniles had hatched and separated from the female, approximately 28 days later. The juveniles were reared in full-sib families until the juveniles averaged approximately 0.5 g wet weight.

At 0.5g the juvenile yabbies were able to be tagged with specific combinations of 8 colours of elastomer (Jerry et al, 2001b). Each animal was identified by two elastomer colours unique to each family. From each family, 100 randomly chosen animals were then transferred to an earthen pond. From the 102 males, 30 full-sib families were identified in this way and these formed the foundation stock for the selection program.

Juveniles were grown in a 0.1 ha pond which had been lined with heavy duty plastic and covered with soil to a depth of approximately 10cm. This was done to facilitate harvest and to reduce the loss of animals at harvest through burrowing. Animals were grown out in the pond for 4 months over the period January to April 2000. Animals were harvested and classified for family, sex and measured for weight, carapace length, abdomen length, and abdomen width.

Family means and estimated breeding values were calculated for those animals where the family could be confidently assigned from the elastomer colours.

2.2 Second, Third and Fourth Generations

For the generations subsequent to the foundation population, selection of animals as broodstock was based on within-family selection.

This procedure was primarily adopted because of the variability between female broodstock in the time at which they spawned. Generally, there was a span of at least 4 weeks over which females came into berry. This procedure was adopted as a compromise between utilising all available genetic variation versus minimising the effects of variation in spawning dates and litter sizes. Within-family selection also facilitated the control of inbreeding in this highly fecund species. In order to more formally control family contributions and maintain a relatively low level of inbreeding, a mating strategy was utilised whereby each generation of females in a family were mated to males from a different family in a formal circular system. Based on a population of 30 families with zero variance in family size, such a procedure is calculated to yield accumulation of inbreeding levels to approximately 0.8% per generation (Falconer 1960). Levels of 1% are considered acceptable levels of accumulation in livestock breeding programs.

Three males and six females with the highest estimated breeding values (EBVs) for growth rate were chosen from each family in the generations born in 2002 (F2), 2003 (F3), and 2004 (F4). Three mating cells per family were initiated to optimise family representation whilst allowing litters to be hatched in individual aquaria.
To facilitate the estimation of genetic improvement in growth rate, a control population was established from the F1 generation by the creation of 30 families and random selection of broodstock for each generation. The control animals were raised in all other respects under the same conditions as the selection line families. Progeny from the control line families were only able to be tagged with a single family identification and thus inbreeding was controlled by limiting family representation in the subsequent generation to a maximum of 50 juveniles.

The mating, rearing, tagging and measurement protocols for each of the F2-F4 generations were similar to that described for the F1 foundation generation.

Full details of the processes and protocols can be found in Jerry et al 2001b and Jerry et al 2002.

2.3 Results

2.3.1 Foundation generation (F1)
Successful matings occurred in 67% of aquaria as evidenced by females being assessed as being berried. However, there was considerable abortion and only 52 of the 109 females carried their litters to full term or produced litters of sufficient size to be utilised in the breeding program. The F1 juvenile crayfish were stocked into a 0.1 ha pond when they were an average weight of 0.59 g (+0.02). Sixty-two percent of these survived and were harvested 78 days later when weighing 30.7 g (+0.02). Male crayfish were significantly heavier than females (32.9 g ± 0.69 vs. 27.5 g ± 0.57, respectively, p<0.001).

Due to loss of elastomers only 83% of individual crayfish (n=1849) could be uniquely identified to their family of origin at harvest. Families varied significantly (p<0.001) with male family means ranging from 16.5 g to 52.6 g, and female values varying from 13.6 g to 40.7 g.

2.3.2 Second Generation (F2)
This generation was produced in the selection line by the choice of broodstock with the highest EBVs within each family. This process resulted in line selection intensity averaging 2.18 for males and 2.15 for females. Establishment of the control line population was achieved by random selection within 19 resulting F1 families that averaged 29 g at harvest.

Mating success in the selection line families averaged 72% although subsequent abortion of litters occurred in 35% of berried females.

One hundred F2 juveniles from each select line family and 480 control line juveniles were stocked into the 0.1 ha pond in January weighing an average of 0.43 g for the select line animals and 0.48 g for the control animals. The crayfish were maintained in the pond until mid-July when they were harvested after 205 days of growth. Survival was 55% but two families had poor survival and insufficient numbers remained for those families to continue the line. Eighty two percent of individuals were able to be assigned to their family of origin and the mean weight after 205 days was 70.1 g (+1.0). The liveweight of the selection and control line crayfish at harvest is summarised in Table 1. The variation in family mean weight is shown in Figure 1.
2.3.3 Third Generation (F3)
As for the first generation, individuals with the highest EBVs from each family were selected as broodstock to produce the new generation. Due to poor survival in two families, only 28 families were represented in the F3 generation.

Associated with a change in broodstock management at the time of berry, the level of abortion was lower in this mating than with the previous generations. Female crayfish were not handled until 24 hours after being noticed to be carrying eggs. Only 25% of the 70% of females to successfully berry lost their eggs.

After a grow-out period in the ponds of 163 days from mid-December to June, the animals were harvested having a survival rate of 55%. 90% of individuals were able to be allocated to their family of origin. Selection line animals were introduced at 0.60 g and at harvest the females weighed 54.4 g compared to control line females weighing 41.0 g, an increase of 32.7%. Similarly select line males were 29.5% heavier at 71.2 g than control line males weighing 55.0 g. (Table 1). The families in the select line showed high levels of between-family variation.

2.3.4 Fourth Generation (F4)
To produce the 4th generation, ninety-three mating groups were established in August 2003 from F3 animals, and these yielded 60 full-sib progeny groups for tagging. There were excellent numbers of progeny per litter, averaging more than 200. After evaluating family representation, 3229 juvenile yabbies were tagged and introduced to the grow-out pond. These represented 27 select group families (2695 animals) and the control group (534 animals).

Animals were harvested in late June after 217 days in the pond. Survival was 37% (1192/3229) which was significantly lower than the 50+% recorded during earlier years of the selection program. Mean weight at harvest of the 1115 select and control animals was 62.8 g. The control animals weighed 58.2 g (256 animals), whilst the select animals were 10.1% heavier at 64.1 g. Of the 1115 animals harvested there were a sufficiently high number of intersex animals for these to be classified separately. Male animals were heaviest (485 at 69.1 g), intersex were of intermediate weight (78 at 65.6 g), whilst the females were lightest (552 at 55.2 g). The interaction between sex and strain was
not significant. The measures of body size – carapace length, tail length and tail width all showed similar differences between the improved strain and the control animals.

Sex effects were likewise of similar magnitude except for tail width where there was no difference between the three sexes for this attribute.

Table 2. Average weight (g) of animals that were assigned to control and selected lines for generations F2-F4

<table>
<thead>
<tr>
<th>Generation</th>
<th>Line (n)</th>
<th>Sex</th>
<th>Grow-out (days)</th>
<th>Weight (g)</th>
<th>Difference (%) in lines</th>
</tr>
</thead>
<tbody>
<tr>
<td>F2</td>
<td>Control (109)</td>
<td>F</td>
<td>205</td>
<td>50.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Select (365)</td>
<td>F</td>
<td>205</td>
<td>62.1</td>
<td>23.7</td>
</tr>
<tr>
<td></td>
<td>Control (155)</td>
<td>M</td>
<td>205</td>
<td>59.6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Select (412)</td>
<td>M</td>
<td>205</td>
<td>83.4</td>
<td>39.9</td>
</tr>
<tr>
<td>F3</td>
<td>Control (141)</td>
<td>F</td>
<td>163</td>
<td>41.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Select (489)</td>
<td>F</td>
<td>163</td>
<td>54.4</td>
<td>32.7</td>
</tr>
<tr>
<td></td>
<td>Control (161)</td>
<td>M</td>
<td>163</td>
<td>55.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Select (531)</td>
<td>M</td>
<td>163</td>
<td>71.2</td>
<td>29.5</td>
</tr>
<tr>
<td>F4</td>
<td>Control (104)</td>
<td>Female</td>
<td>221</td>
<td>48.6</td>
<td></td>
</tr>
<tr>
<td></td>
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<td>Female</td>
<td>221</td>
<td>57.09</td>
<td>17.5</td>
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<td>221</td>
<td>64.7</td>
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<td></td>
<td>Select(58)</td>
<td>Intersex</td>
<td>221</td>
<td>65.7</td>
<td>1.5</td>
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<tr>
<td></td>
<td>Control (132)</td>
<td>Male</td>
<td>221</td>
<td>64.9</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Select (420)</td>
<td>Male</td>
<td>221</td>
<td>70.3</td>
<td>8.3</td>
</tr>
</tbody>
</table>

*All contrasts between Select and Control were significantly different at P<0.01 except for intersex contrast which was NS.
3. Discussion of results

These results show clearly that response to selection for liveweight in the yabby can be successfully achieved. By selecting within families, significant gains were achieved in generations F2 and F3 that averaged around 15%. Coupled with the initial gains achieved by selecting the F1 founder generation, the select animals in generation F3 grew 60-70% faster than the average of all strains taken from the wild. Although the within-family selection strategy did not utilise all available additive genetic variance, the practicality of the strategy together with the reduced confounding by non-genetic effects resulted in a highly effective selection program in these generations. The level of response was significantly greater than that achieved in livestock species, and reflects the much greater fecundity of freshwater crayfish species leading to much greater selection intensities. Combined with quite large phenotypic variation for liveweight, and moderate heritability (Jerry et al. 2002), this translates into rates of change more than 8-fold than can be achieved normally in domestic animal populations.

The achieved gains in generations F2 and F3, are however, in line with the results of selection programs in other marine species and other crayfish species, in particular. Jones et al (2000) reported genetic gains of around 10% per annum in a population of Redclaw (*Cherax quadricaranatus*), and various studies have reported gains above 10% pa in shrimp species (see Jerry et al 2005).

In the F4 generation the gains achieved in the F2 and F3 generations were eroded and a difference of only 10% was maintained. This ranged from 17% in female animals, 8% in male animals and only 1.5% in the animals classified as intersex. Allowing that the lines were 30% or more different based on measurements of the F3 generation, this suggests that the F4 select line animals had deteriorated in comparison to the F3 generation or that the Control population had improved - or a combination of both these changes.

There are several reasons possible for this observation. At harvest there was evidence of many juveniles in the pond, suggesting that females had begun reproducing during the grow-out period. The faster growth of the select line females may have allowed them to initiate reproduction, whereas the slower growing Control line females did not reach this stage during the grow out period. However, the select line females were superior to Control females than were the select line males to Control males, so this does not support this conclusion.

The growth rates achieved by the F4 generation animals were considerably slower than that demonstrated by the F2 and F3 generation animals. This situation, when combined with evidence of a mortality of 63%, suggests that environmental conditions may have been such that the F4 generation select animals were unable to express their superiority due to environmental constraints. The presence of a higher level of intersex animals than seen in previous generations also suggests that different conditions were applicable to the grow-out of the F4 animals.

With the rotational family mating strategy employed in the program it is unlikely that inbreeding depression could be a source of the reduced genetic gain observed in the F4 generation. This contention is supported by the phenotypic coefficient of variation over all animals being 41%. In addition, the between-family variation was still highly significant. A further mating of F4 and control animals will assist in understanding the basis for the apparent loss of genetic gain in the F4 generation.
3.1 Implications for relevant stakeholders

3.1.1 Commercial Growers
There are many levels of entry to the farming of yabbies, from simple harvesting of farms dams without any attempt to provide improved nutrition or water quality, through to the more sophisticated technically demanding production in purpose built ponds, utilising controlled nutrition and water quality control. In its simplest form, where the family can simply harvest from their existing farm dams three or four times a year, yabby farming can be profitable.

As the level and sophistication of production increases then costs also increase significantly. The costs of purpose built ponds, labour and feed are critical issues. However, economic analyses suggest reasonable internal rates of return can be achieved whilst highlighting the impact that variability of price and yield (per ha of water) can have on profitability.

According to the Food and Agriculture Organisation (FAO), aquaculture has become the fastest growing food-producing sector over the last 30 years. Aquaculture has the potential to become an important industry and boost economic development in regional Australia. Better selective breeding programs will help achieve this.

In addition, yabby aquaculture may assist governments, industries and communities increase the productivity of water for combined social, economic and environmental outcomes, and ensure a sustainable use of our water resources.

3.2 Recommendations
The density with which dams are stocked with juvenile animals can influence turn-off rates in farm dams. In areas where annual rainfall is particularly seasonal, dams can be emptied and cleaned out of adult yabbies on an annual basis.

Where juveniles are sufficiently large enough to be sexed, increased production can be achieved by the raising of single sex cohorts. Where sexing is conducted efficiently, this strategy results in an absence of reproductive activity in the pond and consequent losses in production.

In response to public expectation of how the aquaculture industry conducts its activities, animal welfare and food safety strategies are increasing. Several states have developed Codes of Conduct and Best Practice for the production and marketing of crayfish. Adherence to these codes may lead to increased consumer acceptance and possibly higher levels of productivity and profit.

An objective assessment of the potential of larger scale yabby farming may conclude that achieving sustainable profitability will be a primary function of:
- The marketing arrangements that are able to be put in place
- The capacity to organise a system of year round supply of commercial sized animals
- The capacity to guarantee availability in times of drought