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Growth and Survival of *Cherax destructor* and *Bidyanus bidyanus* Stocked in a Communal Aquarium System

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ABSTRACT

Polycultural aquaculture typically utilises a mix of low trophic level species to increase yield above that which can be obtained from a single species. Low trophic level species are not widely accepted for consumption within Australia, so this study focussed on two species that have market acceptance, the yabby (*Cherax destructor*) and the silver perch (*Bidyanus bidyanus*). Laboratory scale trials examined the effect of each species on the growth and survival of the other species as well as the role of shelter for crayfish in this system over a 13.5 week period. Neither species negatively impacted the growth of the other, however, survival was negatively impacted. Shelter enhanced crayfish survival, although fish survival was impacted in those treatments. A higher total biomass was harvested from polyculture treatments than monoculture treatments. The positive results warrant further investigation at the scale of mesocosm, prior to large-scale pond trials.

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INTRODUCTION

Polycultural aquaculture typically utilises a variety of non-competing, low trophic level, species (e.g., detritivores and herbivores). The mix of species results in higher productivity and a more efficient use of resources compared to monoculture (Folke and Kautsky 1992; Tian et al. 2001). However, low order fish species are not widely accepted for consumption in Australia, therefore, for polyculture to be successful on a large scale in Australia, a different suite of species needs to be selected.

Crustacean/finfish cultures are one grouping which shows promise for polyculture, as both are widely accepted for consumption (Danher et al. 2007; Perry and Tarver 1987; Wohlfarth et al. 1985). In Australia, crayfish in the genus *Cherax* may be suitable for this type of culture and have been the subject of national and international research. The polyculture of *Cherax quadricarinatus* von Martens with tilapia has received attention from a number of authors (Barki et al. 2001; Brummett and Alon 1994; Karplus et al. 1995a; Kotha and Rouse 1997; Ponce-Marbán et al. 2006; Rouse and Kahn 1998) and is supported by positive economic simulations demonstrating increased profitability over monoculture production (Ponce-Marbán et al. 2006).

Research into the polyculture of crayfish with finfish in Australia is limited. A single study has investigated polyculture of *C. quadricarinatus* and *Bidyanus bidyanus* (Mitchell) (Jones and Ruscoe 1996) whilst a number of published studies have been undertaken into the polyculture of *Cherax tenuimanus* Smith (*C. cainii* Austin *sensu stricto,* as referred to throughout the rest of this document) and *B. bidyanus* (Storer et al. 2004, Whisson 1996; 1999, 2006). A commercial scale production trial found that polyculture of *C. quadricarinatus* and *B. bidyanus* yielded similar economic value as monocultures of *C. quadricarinatus*, however, this trial suffered poor survival of fish due to handling. Had survival been higher, economic return from polyculture would have been significantly greater (Jones and Ruscoe 1996). Despite *Cherax destructor* Clark having similar traits as these two crayfish species, not a single study into the polyculture of *C. destructor* and finfish could be found.

Any assessment of between species interaction within polycultures of crayfish and finfish can be examined from two perspectives; the effect of fish on crayfish, and the effect of crayfish on the fish. Studies of *C. quadricarinatus* and tilapia polyculture have found varying impacts of tilapia on *C. quadricarinatus*. Brummett and Alon (1994) found the presence of tilapia had no

impact on growth of *C. quadricarinatus*, however, other studies have found tilapia to negatively affect growth of *C. quadricarinatus* (Barki et al. 2001; Kotha and Rouse 1997; Rouse and Kahn 1998). The magnitude of the negative effect varied depending on the size differential between the species (Barki et al. 2001). The negative influence of fish is not necessarily through direct predation. Barki et al. (2001) suggested the negative effect was most likely a result of the fish outcompeting the crayfish for food, however, just the presence of fish, even when caged, resulted in decreased growth and survival of *C. quadricarinatus* (Kotha and Rouse 1997). The negative impact may result from the presence of predatory fish odour impacting crayfish behaviour (Height and Whisson 2006). Such changes in behaviour may cause the crayfish to seek shelter and reduce feeding, in effect resulting in a higher density of crayfish which could lead to an increase in agonistic interactions (Barki et al. 2001).

In Australia, studies have focussed on rearing *C. quadricarinatus* or *C. cainii* with the native silver perch, *B. bidyanus*. Preliminary trials found *B. bidyanus* to have a negative effect on juvenile *C. quadricarinatus* produced in the pond as a secondary cohort, although this effect was not evident on the primary cohort (Jones and Ruscoe 1996). Whisson (1996) found *B. bidyanus* predate on both juvenile and adult *C. cainii*, resulting in reduced survival of both size classes. The addition of an aquatic plant, *Vallisneria* sp., abolished the predatory effect of *B. bidyanus,* as *C. cainii* were able to use the plant for predator avoidance (Whisson 1996). Production scale trials found mean weight and population structure were not affected by presence of *B. bidyanus* (Jones and Ruscoe 1996).

The effect that crayfish have on fish within polyculture systems is also of interest, however, many polyculture studies have not included a monoculture fish treatment as a control to compare how fish respond to the presence of crayfish (Kotha and Rouse 1997; Whisson 1996, 1999). Of the studies that have included this treatment, none found crayfish to negatively affect fish survival (Jones and Ruscoe 1996; Rouse and Kahn 1998). The effect of crayfish on fish growth, however, has differed between studies. Brummett and Alon (1994) found *C. quadricarinatus* to negatively affect tilapia growth, however, Barki et al. (2001) found it to positively affect tilapia growth. Negative interactions may be reduced by the use of cages, and *B. bidyanus* may be ideal candidates for this type of polyculture as they grow well in cages (Rowland et al. 2004). Fish can be stocked in cages at densities up to 200 m^{-3} with no negative effect on survival or growth, and even higher densities may be possible (Rowland et al. 2004; Rowland et al. 2006).

The aim of our study was to undertake the first investigation into the feasibility of *C. destructor* and caged *B. bidyanus* polyculture. The objective was to examine the effect of each species on the growth and survival of the other species as a trial prior to large-scale experiments. We examined whether shelter improved crayfish growth and survival and whether shelter was of more value to crayfish growth and survival in the presence of fish. Traditional polyculture can utilise species that benefit from the waste of the others, so to investigate this in the laboratory, we examined whether fish faecal material conferred a growth advantage to *C. destructor* when raised in polyculture. Results of this study will provide an initial assessment on the feasibility of *C. destructor* and *B. bidyanus* polyculture.

MATERIALS AND METHODS

Study Site

An indoor, recirculating aquarium system at CSIRO, Livestock Industries, Chiswick, NSW, Australia, was used to undertake this study. The system consisted of three banks, each containing 32 aquaria (890 × 490 × 290 mm). Water quality was maintained through a separate biological filtration system and UV steriliser for each of the three aquarium banks. Fluorescent lights were set to provide a 14:10 light:dark cycle to simulate the summer photoperiod. Water temperature was heated to 25°C, a temperature that would provide ideal growing conditions for both *C. destructor* and *B. bidyanus*. Aeration was provided 24 hrs·day^{-1} for the duration of the experiment.

The system was filled with dechlorinated scheme water. To condition the water, Calcium nitrate (1.5 kg), agricultural lime (1.5 kg), gypsum (1 kg), dolomite (1.5 kg) and sodium chloride (5 kg) were added to the 600 L sump. A thin layer (25 mm) of washed river gravel (~7 mm diameter) was placed in the bottom of each aquarium to provide animals with a complex substrate. The system was allowed to cycle for four weeks to condition the filter media in the absence of biota and prior to initiation of the experiment.

Experimental Design

Aquaria involved in this study were separated from adjacent treatments by an empty aquarium. This restricted any potential negative visual effects of each species on the other from neighbouring aquaria. Aquaria were randomly assigned to one of eight treatments in a blocked design (Table 1) with six replicates of each. Treatments containing crayfish had either shelter or no shelter. Each shelter consisted of three sheets of corrugated polycarbonate material (40 × 22 cm), fixed to one another trough to crest. This created 15 hollows for crayfish to utilise as shelter. Treatments containing fish either allowed crayfish access to fish faecal material through changes in cage design or did not. Cages were (60 × 30 × 15 cm, 6 mm plastic mesh) and attached to floats to suspend the cage 15 cm above the substrate. Cages assigned to the no faecal material treatment were lined with a clear plastic that finished approximately 4 cm below the water surface to allow water to flow into the cage, whilst still allowing any visual or chemical communication between species. This lining trapped any fish faecal matter and was siphoned frequently. Water quality was measured weekly for ammonia, nitrate and nitrite, and remained within acceptable limits for the duration of the experiment.

Bidyanus bidyanus fingerlings were sourced from Grafton Aquaculture Centre DPI, NSW. Eight fish (mean weight = 2.96 g ± 0.09 SE) were stocked into each cage providing an effective density of 296·m^{-3}, high enough to break down the formation of dominance hierarchies (Rowland et al. 2006). Juvenile *C. destructor* (mean 0.45 g ± 0.02 SE) from a single family were stocked at a rate of 9·$tank^{-1}$, giving an effective density of 20.6 animals·m^{-2}. The *C. destructor* strain utilised in this study were from a strain selected for improved growth rates (Jerry et al. 2005).

Table 1. Abbreviations for fish and crayfish experimental treatments. The experimental design of our study was not fully factorial as indicated by the shaded box where both crayfish and fish are absent. SP = crayfish with shelter, SA = crayfish without shelter, FP = fish in plastic line cages, FM = fish in mesh cages without plastic lining.

		Crayfish		
		Absent	**Shelter Present**	**Shelter absent**
Fish	**Absent**	—	SP	SA
	Plastic lined cage	FP	FPSP	FPSA
	Mesh cage	FM	FMSP	FMSA

Table 2. Effect of cage type on fish production parameters (mean ±SE).

Treatment	Mean weight (g)*	Biomass (g)*	Survival (no.)*
Mesh cage	8.71 ± 0.32	15.14 ± 0.41	1.78 ± 0.51
Plastic lined cage	6.92 ± 0.29	16.98 ± 0.38	2.46 ± 0.46

* There were no significant ($P < 0.05$) differences in the growth parameters of fish, between the two cage types.

Table 3. Effect of crayfish on fish production parameters (mean ±SE).

Treatment	Mean weight (g)	Biomass (g)[1]	Survival (no.)[1]
Crayfish absent	6.92 ± 1.38	21.88 ± 0.49[a]	3.16 ± 0.61[a]
No shelter	8.32 ± 1.51	15.14 ± 0.49[ab]	1.82 ± 0.62[ab]
Shelter	7.94 ± 1.29	11.75 ± 0.39[b]	1.41 ± 0.42[b]

[1] Differences in superscript represent significant ($P < 0.05$) differences.

Table 4. Effect of shelter on crayfish production parameters (mean ±SE).

Treatment	Mean weight (g)	Biomass[1]	Survival (no.)[1]
No shelter	6.92 ± 0.37	17.78 ± 0.31[a]	2.69 ± 0.44[a]
Shelter	4.90 ± 0.30	24.55 ± 0.29[b]	5.01 ± 0.24[b]

[1] Differences in superscript represent significant ($P < 0.05$) differences.

Table 5. Effect of fish on crayfish production parameters (mean ±SE).

Treatment	Mean weight (g)	Biomass	Survival (no.)[1]
Fish absent	5.13±0.42	22.39±0.36	4.37±0.54[a]
Mesh cage	6.76±0.49	19.05±0.42	2.95±0.57[b]
Plastic lined cage	5.63±0.36	20.89±0.35	3.72±0.38[ab]

[1] Differences in superscript represent significant ($P < 0.05$) differences.

Crayfish were fed a formulated pellet containing 30.3% crude protein (CP). This pellet has previously been found to provide suitable growth rates and is described in Duffy et al. (2011). To ensure fish did not consume the pellet, a feeding tube was inserted into the tank and used to deliver food to the bottom of the tank. To standardise feeding techniques and food distribution this technique was also used in treatments where fish were absent. Crayfish were fed at a rate of 5% of their biomass, three times a week for the duration of the 13.5 week experiment. Animals were weighed every four and a half weeks and the food ration adjusted appropriately to reflect overall biomass at weighing.

To prevent crayfish accessing food intended for *B. bidyanus*, fish were fed a commercially available floating pellet (40% CP, 3 mm). Fish were fed to satiation three times per week at the same time as the crayfish. Any floating pellets remaining in the tank after feeding were removed with a dip net. The combination of feeding methods ensured each species received only the food they were allocated.

Data Analysis

All data were log transformed to satisfy the assumptions of normality and equality of variance. Survival and biomass data for fish and crayfish were analysed using a repeated measures

ANOVA. A regression analysis was used to examine weight data of crayfish and fish for any relationship with survival, independent of treatment effects. This test was significant for both, therefore, weight data were analysed using a repeated measures ANCOVA with final survival used as the covariate. Post-hoc testing with a Tukey's test was used to determine where differences occurred.

RESULTS

Fish

Mortality of fish occurred throughout the study and after ten weeks, 50 to 80% of fish had died. Survival of *B. bidyanus* was not affected by cage type (Table 2), however, it was affected by the presence of *C. destructor* ($P < 0.05$) (Table 3). Fish in treatments without crayfish had higher survival than treatments containing crayfish with shelter (FP, FM vs. FPSP, FMSP) ($P < 0.05$). There was no difference in the survival of fish between treatments containing crayfish, regardless of the presence or absence of shelter (FPSP, FMSP vs. FPSA, FMSA). Nor was there a difference in fish survival between treatments where crayfish were absent and those containing crayfish without shelter (FP, FM vs. FPSA, FMSA). There was no interactive effect of cage type and crayfish treatments on fish survival.

Biomass of *B. bidyanus* decreased from the initial stocking as fish numbers decreased. However, biomass for all treatments had increased from its lowest point by the final sampling period. Final biomass remained lower than the initial biomass of animals stocked into the study. Cage type had no effect on biomass of fish (FP, FPSP, FPSA vs. FM, FMSP, FMSA) (Table 2), however, biomass was greater in treatments where crayfish were absent than treatments containing crayfish with shelter (FP, FM vs. FPSP, FMSP) ($P < 0.05$) (Table 3). There was no difference in biomass of fish in treatments containing crayfish with or without shelter (FPSP, FMSP vs. FPSA, FMSA) (Table 2). Nor was there a difference in fish biomass between treatments without crayfish and those containing crayfish without shelter (FP, FM vs. FPSA, FMSA) (Table 3). Cage type and crayfish treatments had no interactive effect on fish biomass.

Weight was not affected by cage type (FP, FPSP, FPSA vs. FM, FMSP, FMSA) or crayfish treatments (FP, FM vs. FPSP, FMSP vs. FMSP, FMSA) (Table 2 and Table 3). There was no interaction between cage type and crayfish treatments for weight.

Crayfish

Both shelter (SP, FPSP, FMSP vs. SA, FPSA, FMSA) and fish treatments (SP, SA vs. FPSP, FPSA vs. FMSP, FMSA) had a significant impact on the survival of *C. destructor* ($P < 0.05$) (Table 4 and Table 5), however there was no interaction between treatments. The presence of shelter enhanced survival of *C. destructor* (SP, FPSP, FMSP vs. SA, FPSA, FMSA) ($P < 0.05$) (Table 4). Survival of crayfish was greater where fish were absent than treatments where fish were present in mesh cages (SP, SA vs. FMSP, FMSA) ($P < 0.05$) (Table 5). There was no difference in survival of *C. destructor* between treatments without fish and treatments with fish in plastic lined cages (SP, SA vs. FPSP, FPSA), nor was there a difference in survival of *C. destructor* between either fish cage treatment (FPSP, FPSA vs. FMSP, FMSA).

Biomass of crayfish was significantly higher in treatments with shelter than treatments without shelter (SP, FPSP, FMSP vs. SA, FPSA, FMSA) ($P < 0.05$). Biomass of *C. destructor* was not affected by the absence of fish, or by having access to fish faecal material (SP, SA vs. FPSP, FPSA vs. FMSP, FMSA). There was no interaction between shelter and fish treatments.

Weight of *C. destructor* at completion of the study was significantly correlated with final survival ($P < 0.001$, $R^2 = 0.794$ (Cubic regression)) regardless of treatment. Therefore, further weight analysis was undertaken using final survival as a covariate. The results of this analysis revealed that the mean weight of *C. destructor* was independent of all treatments and there was no interaction (Table 4 and Table 5). Coefficient of variation of weight was also independent of treatment effects.

DISCUSSION

The presence of *C. destructor* and *B. bidyanus* in the same aquarium had no effect on the growth rate of the other. Crayfish were conferred no growth advantage from having access to fish faecal material as an extra source of nutrition. This is not surprising given crayfish raised on the same diet as the one used in this experiment, showed no difference in growth between animals with and without access to naturally occurring food sources (Duffy et al. 2011). This is an important result, as in trials where a growth advantage for one species has been found (e.g., Barki et al. 2001; Storer et al. 2004; Whisson 1996, 2006) it may simply be due to a species consuming some of the ration intended for the other, as reported by Barki et al. (2001). As such, it highlights the need for well-structured experiments such as the present study, to specifically examine the effects and interactions in polyculture systems.

Communal culture of *C. destructor* and *B. bidyanus* had a negative impact on the survival of each species. Survival of fish was negatively affected when crayfish were present in conjunction with shelter, however, treatments containing crayfish without shelter did not affect fish survival. No other studies have found crayfish to affect fish survival (Barki et al. 2001; Brummett and Alon 1994; Jones and Ruscoe 1996; Rouse and Kahn 1998). Observations suggest that the negative effect of crayfish on fish was magnified by formation of a dominance hierarchy in *B. bidyanus*. The largest fish in a cage was observed over a number of days to regularly chase the smallest fish. The fins of the subordinate fish became tattered and the animal would become lethargic, resting on the bottom of the cage. Such situations can lead to greater energy expenditure of the fish, health problems and chronic stress (Wedemeyer 1996). In the present study, the subordinate fish may have been particularly vulnerable to further harassment by crayfish climbing on the cage. The higher density of crayfish in treatments with shelter could have resulted in increased harassment and eventually higher mortality of the subordinate fish. Most fish found dead in cage treatments showed signs that crayfish had fed on the carcass.

The hierarchical formation in *B. bidyanus* was unexpected. Dominance hierarchies are not uncommon in fish stocked at medium densities (Petit et al. 2001; Suresh and Kwei Lin 1992)

and even in *B. bidyanus* at densities of 25 or 50 fish·m^{-3} (Rowland et al. 2006). We stocked fish at a relative density of greater than 200 fish·m^{-3} and these high densities have been shown to reduce dominance hierarchy formation and increase survival (Rowland et al. 2006). Therefore, hierarchy formation in the present study is unlikely to be a result of the selected effective stocking density, but rather, it is probably a result of the low number of fish (n = 8) that were stocked into each aquarium due to the scale of the experiment.

Just as crayfish had an effect on fish survival, the inverse was also true. Survival of crayfish was reduced in treatments containing fish and where crayfish had access to fish faecal material. Kotha and Rouse (1997) also found survival of *C. quadricarinatus* was lower in polyculture with tilapia, however, it was not a result of predation as the negative effect on crayfish survival was the same in treatments with caged or free range fish. Contrary to these results, other studies have found no difference in survival of *C. cainii* between treatments with fish in cages and treatments without fish.

The addition of shelter in our study resulted in increased crayfish survival and biomass. Shelter did not affect weight, therefore, the increase in crayfish biomass was a result of increased numbers of animals. Findings on the benefit of shelter to crayfish have differed between studies (benefit: Geddes et al. 1993; Jones and Ruscoe 1996; Karplus et al. 1995b vs. no benefit: Verhoef and Austin 1999; Jones et al. 2002). One difficulty in comparing results of shelter studies is the use of different shelter types, sizes and the number of spaces available for sheltering. Along with structure, possibly the most important factor affecting the role of shelter is the ratio of shelter spaces to animals. We stocked *C. destructor* at a density of 20.6 animals·m^{-2} and provided shelter at a rate of 1.67 shelters per animal. This ratio may be much higher in studies where shelter enhances growth and/or survival (Geddes et al. 1993; Jones and Ruscoe 1996; Karplus et al. 1995b) as opposed to those studies that find no effect (Jones et al. 2002; Verhoef and Austin 1999).

Growth of each species was not impacted by the presence of the other, thus supporting the potential for this method to increase production. However, the low survival rate observed in this study will need to be overcome. Low survival may have been an artefact of scale and it is recommended that larger mesocosm scale trials be undertaken to determine if this is the case.

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