CULTURE OF THE AUSTRALIAN RED-CLAW CRAYFISH *(CHERAX QUADRICARINATUS)* IN ISRAEL
II. SECOND GROWOUT SEASON OF OVERWINTERED POPULATIONS

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Abstract

Redclaw crayfish *(Cherax quadricarinatus)* were collected after a first growout season and held over winter in earthen ponds under a plastic covering. At the end of the winter, separate male and female populations and mixed populations were stocked in earthen ponds for a second growout season of 226 days. The slight differences in weight between males and females at the end of the first growout season were substantially enhanced during the second growout season. After the second growout season, crayfish weighing over 100 g were significantly more abundant in the male-stocking ponds than in the mixed-stocking ponds and were scarce among the specimens harvested from the ponds stocked with females. Survival rates of the crayfish cultured for a second season were calculated to be at least 78% in the all-male stocking and 86% in both the female and mixed-sex stockings. Crayfish weighing less than 15 g, representing in-pond reproduction during the second growout season, comprised over 30% of the harvest in both the mixed-sex and female stockings, and less than 7% in the male stocking. Growing male *C. quadricarinatus* for a second growout season thus seems promising. However, development of the appropriate aquaculture technologies for monosex population formation and overwintering is needed.

Introduction

The redclaw crayfish *Cherax quadricarinatus* (von Martens) is a tropical species found in the river systems of northern Queensland and the Northern Territory, Australia, and Papua New Guinea (Jones, 1990). The fast growth of this species and its tolerance to a wide range of temperatures, from 5°C to 42°C, make it a good candidate for temperate-zone aquaculture (Ackefors, 1994). An additional advantage is the wide temperature range (22.5-31.5°C) for optimal growth, i.e., at least 70% of the maximum growth rate (Jones, 1990). At two years of age, *C. quadricarinatus* specimens weigh 250-300 g and can reach a maximum weight of 400-

600 g (Ackefors, 1994). As a result of its potential as an aquacultural crop, *C. quadricarinatus* was introduced to the Australian aquafarm industry in the mid-1980s and later to most other continents (Medley et al., 1994).

A common strategy for increasing the production of tropical crustaceans in temperate regions is to stock the ponds as early in the season as possible with nursed juveniles that are as large as possible (Sandifer and Smith, 1985). However, due to the relatively short growout season in temperate zones, it may be that this crayfish is being harvested while still in a potentially fast growing phase, before they have exhausted their full growth capacity.

In Israel, after a relatively short growout period in earthen ponds (92 days, average weight at stocking approximately 3 g), *C. quadricarinatus* males reached an average weight of 34.5 g, while females reached 31.9 g (Karplus et al., 1995). It has recently been reported that after 10 months of growout in Australia, males in all-male populations attained a greater mean weight than specimens grown in all-female or mixed populations (Curtis and Jones, 1995).

The objective of the present study was thus to assess the growth potential of large overwintered *C. quadricarinatus* specimens in segregated versus mixed populations in a second growout season under temperate-zone conditions.

Materials and Methods

The crayfish were propagated in hatcheries at the Agricultural Research Organization, Bet Dagan, and the Aquaculture Research Station, Ministry of Agriculture, Dor. The crayfish (0.1-2 g each at stocking) were cultured during the first growout season in 400 m^2 earthen ponds, at a density of approximately 2,200 crayfish per pond. Five silver carp *(Hypophthalmichthys molitrix)* were stocked in each pond as sanitary fish to prevent algal blooming (Milstein, 1992). The crayfish were harvested after 160 days, with an average weight of 43 g (average survival 60%). The crayfish were then transferred to two 250 m^2 earthen ponds, covered with a clear plastic sheet, where they were held over winter, November 12, 1995 - March 31, 1996 (min/max temperatures 16/21°C). At the end of March, the crayfish were stocked into 330 m^2 earthen ponds that had been empty for at least three months prior to stocking. The ponds were stocked at a density of 330 crayfish per pond for a second growout season of 226 days. Two ponds were stocked with randomly selected mixed-sex populations, having an average weight of 38 g per crayfish. The remaining crayfish were separated into male and female populations according to differences in the location of their genital openings and the characteristic red patch on the outer margin of the cheliped propodus of the males (Thorne and Fielder, 1991). Intersex individuals possessing both male and female genital openings (Sagi et al., 1996) were rejected. We aimed at reaching complete monosex populations. However, the stocking might have been slightly different due to human errors or crayfish migration at a later stage. Six similar ponds were stocked, three with males and three with females (average weight at stocking 42 g and 38 g, respectively). Ten silver carp, weighing 15 g each, were stocked in each pond. Commercial crayfish pellets (30% protein) were supplied manually six days a week, at approximately 2% of the estimated total crayfish biomass. Minimum and maximum water temperatures during April were 17° and 22°C, respectively. Temperatures rose in May and early June (minimum and maximum temperatures 25-28°C and 28-32°C, respectively). They remained high until early September, after which they decreased rapidly, reaching the April values by the second half of October. To prevent problems associated with low dissolved oxygen, the ponds were aerated daily for 12 h by means of 0.5 hp paddlewheel aerators. Water was added to the ponds (maximum depth 1 m) only to make up for losses due to seepage and evaporation.

The crayfish were harvested at the end of the second growout season, each specimen over 15 g was weighed, and its sex was determined as described above. Animals under 15 g were counted and weighed in bulk. Statistical significance of the differences among treatments (α=0.05) was determined using a one-way ANOVA and the Duncan multiple range test.

Results

Fig. 1 shows the differences between the males and females in the experiment. The males were slightly larger than the females at stocking (Fig. 1-I), and this difference was substantially enhanced during the second growout season (Fig. 1-II), with the males having a much higher average weight than the females. In addition, a considerable number of the specimens in the all-male stocking (31% of the population over 50 g) had weights of 150-300 g and relatively large and wide claws (Fig. 1-III). Such specimens were not found among the females, which scarcely reached 100 g by the end of the second growout season.

The above-mentioned differences in weight are evident in the data for the harvested popu-

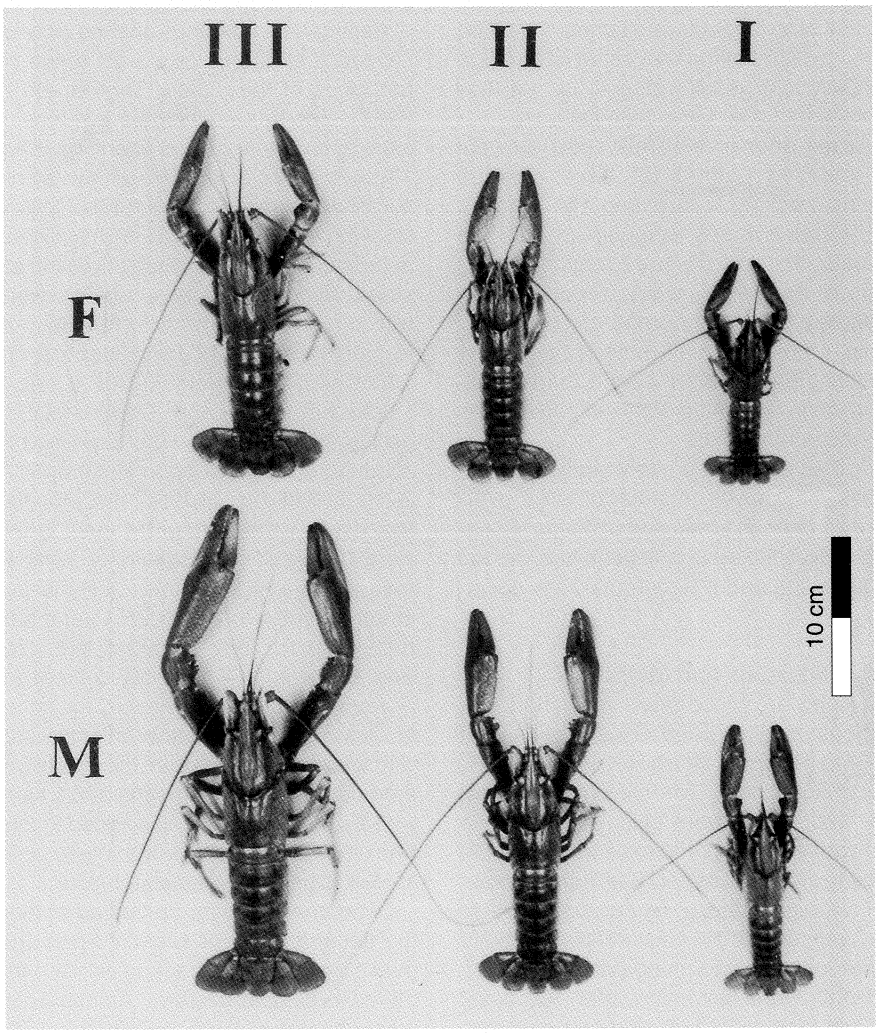

Fig. 1. *Cherax quadricarinatus* males (M) and females (F): (I) specimens after being held over winter, at the beginning of the second growout season; (II) specimens of approximately average harvest size at the end of the second growout season; (III) record-weight specimens at the end of the second growout season. The males in this figure weighed 42, 150 and 297 g, and the females weighed 38, 80 and 149 g.

lations presented in Table 1. The greatest difference ($p<0.02$) was found in the number of harvested crayfish weighing more than 100 g, which comprised 15.4% of the animals harvested from the all-male ponds and only 0.4% of the harvest from the all-female and 1.2% (mostly males) from the mixed-sex ponds. These large specimens comprised 57% of the total biomass of the male stocking at the end of the second growout season (Table 2), which was a significantly ($p<0.03$) larger share of the biomass than that in the female (4%) and mixed (13%, mostly males) stockings.

The fraction of the population weighing above 50 g most likely included the specimens that were originally stocked into the ponds whereas those weighing under 50 g were probably produced as a result of in-pond reproduction during the second growout season. Therefore, the number of crayfish over 50 g may serve as an indication of the survival rates of the stocked crayfish, which were at least 78%, 86% and 86% of the originally stocked 330 crayfish for the all-male, all-female and mixed stockings, respectively. The all-male stocking contained at least 7% females, while the all-female stocking contained at least 24% males (Table 1) due to inaccurate sorting of the sexes, errors in stocking, and/or crayfish migration between the ponds due to the absence of fences. The sex ratio in the mixed stocking and in specimens weighing between 15 and 50 g was close to 1:1.

The difference in growth of the male and female specimens is further demonstrated by Fig. 2 which shows distinct size distributions in the animals weighing above 50 g in the different treatments. Males from the all-male ponds had the widest, relatively normal, size distribution with an average weight of 137 g. The size distribution of the females from both the all-female and the mixed stockings was positively skewed. The distribution of the male fraction of the mixed population was narrower than that in the all-male stocking and more positively skewed, probably due to the inclusion of some newly recruited males in the lower weight groups and the higher density of the mixed sex treatment.

The second seasons' harvest from the

Table 1. Numbers (± SD) of *Cherax quadricarinatus* crayfish, within weight categories, at the end of the second growout season.

Weight	*Male stocking*		*Female stocking*		*Mixed stocking*	
	Male	*Female*	*Male*	*Female*	*Male*	*Female*
Over 150 g	81±40	0	1±1	0	13±14	0
100-150 g	87±6	1±2	7±5	15±13	39±8	8±6
50-100 g	67±25	22±34	73±47	187±7	95±16	128±62
15-50 g	186±133	182±139	360±114	354±77	315±100	338±120
Under 15 g	470±392		4,509±1,978		4,146±3,287	
Total >100 g	169		23		60	
Total>50 g	258		283		283	
Total <50 g	838		5,223		4,799	
Total	1,096		5,506		5,082	

Numbers represent means of 3 ponds stocked with 330 crayfish for the male and female stockings and 2 ponds stocked with 330 crayfish for the mixed stocking. Crayfish under 50 g are assumed to be the result of in-pond reproduction and not those which were stocked in the pond at the beginning of the experiment.

Table 2. Weight of *Cherax quadricarinatus* crayfish at the end of the second growout season.

Weight	*Male stocking*		*Female stocking*		*Mixed stocking*	
	Male	*Female*	*Male*	*Female*	*Male*	*Female*
Over 150 g	16,086±8,638	0	84±118	0	2,430±2,681	0
100-150 g	10,681±913	140±159	781±624	1,623±1,508	4,789±757	903±665
50-100 g	5,290±1,814	1,397±2,172	4,597±2,814	12,898±664	6,509±637	8,202±3,892
15-50 g	5,182±3,977	5,296±4,425	10,889±3,347	11,582±2,535	9,934±2,640	11,323±3,474
Under 15 g	3,131±2,494		21,030±226		19,193±12,101	
Largest individual found	296.8	106.9	167.2	149.2	247.9	146.6
Mean wt for specimens>100 g	159.3	-	108.1	108.2	138.8	112.8
Total biomass for specimens >100 g	26,767	140	865	1,623	7,219	903
Mean wt for specimens>50 g	136.6	66.8	68.3	72.1	93.7	66.9
Total biomass for specimens >50 g	32,057	1,537	5,462	14,521	13,728	9,105
Mean wt for specimens<50 g	16.3		8.3		8.4	
Total biomass for specimens <50 g	13,609		43,501		40,450	
Total biomass	47,203		63,484		63,283	

Values are presented in g ± SD.

mixed-sex and all-female stockings contained, on average, more than 4,000 small (under 15 g) crayfish per pond, which were generated from in-pond reproduction during the second growout season. Each all-male pond contained an average of only 470 such small crayfish (Table 1). These differences are well illustrated in Table 2, showing that in the all-male stocking, a lower portion (6.6%) of the average total biomass was composed of small crayfish compared with the all-female (33.1%) and mixed stockings (30.3%). However, due to high variation, the differences between the treatments in terms of number and biomass of specimens under 15 g were not statistically significant ($p>0.12$ and $p>0.09$, respectively).

Discussion

This study describes the first attempt to maintain a large *C. quadricarinatus* population over the winter in a temperate zone, with the aim of facilitating a second growout season. One of the most significant characteristics of the harvest at the end of the second growout season was the large biomass of crayfish weighing over 100 g in the male-stocking ponds. Our results show that the dimorphic growth previously noted in *C. quadricarinatus* (Medley and Rouse, 1993; Karplus et al., 1995; Curtis and Jones, 1995) was augmented during the second growout season. The results further stress the potential advantage of growing all-male monosex populations of crayfish for a second

growout season. In contrast to our investigation, a previous study of a monosex culture of *C. quadricarinatus* during the first growout season (Curtis and Jones, 1995) did not provide such clear-cut findings. In that study, an effective comparison of male and female growth rates, survival and yields could not be made since the crayfish were stocked at a small size, not allowing a distinction between stocked and newly recruited individuals at the end of the season.

Culture of monosex populations is a common procedure in farmed-animal husbandry. This production strategy has been applied suc-

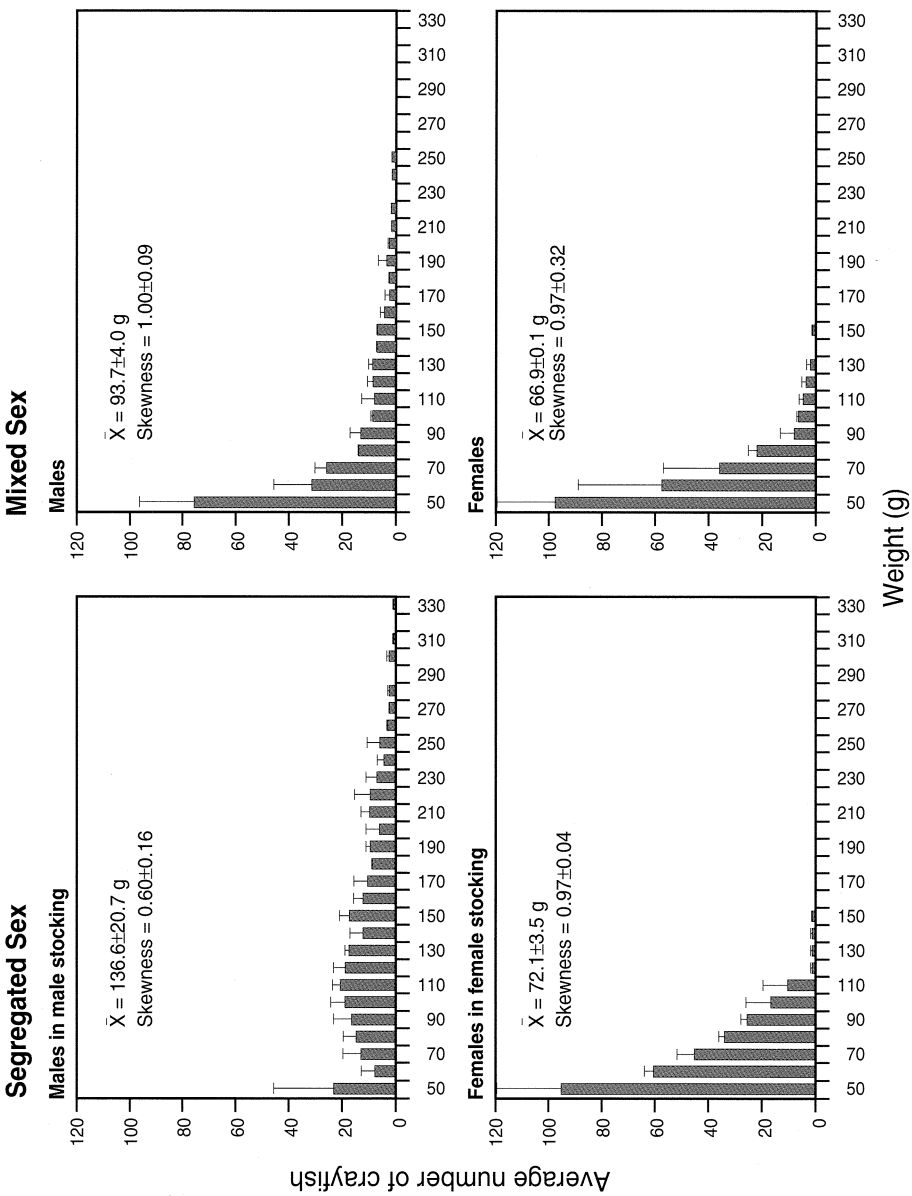

Fig. 2. Weight distribution of *Cherax quadricarinatus* populations (>50 g) at the end of the second growout season. The bar in each weight category represents the mean value of the replicates of each treatment. Error bars represent standard deviation.

cessfully for fish aquaculture (Mires, 1977; Tayman and Shelton, 1978). When tested for culturing the crustacean *Macrobrachium rosenbergii,* it also resulted in an improvement in marketable yields (Sagi et al., 1986; Cohen et al., 1988; Hulata et al., 1988). As a result, several attempts have been made to study sex heritability in crustaceans with the aim of developing a technology to produce crustacean monosex populations as an aquacultural procedure (Sagi and Cohen, 1990; Malecha et al., 1992). Hand-sexing of a *C. quadricarinatus* population for stocking a second growout season is feasible, since the characteristic red patch on the propodus of the males may be used as an early marker (Thorne and Fielder, 1991). However, this procedure is labor intensive, and the need for further research and development to establish a more feasible technology is evident.

Another marked characteristic of the second years' harvest was the high proportion of newly produced juveniles, which are completely absent in ponds stocked with juveniles (1-5 g) under Israeli culture conditions. *C. quadricarinatus* specimens attain sexual maturity within 7-9 months (Rouse et al., 1991). Thus, most of the crayfish stocked for the second growout season (over eight months old) were capable of reproducing in the pond. The highest contribution of in-pond breeding was found in the female ponds (due to the presence of males that had migrated or been incorrectly sorted) and the mixed-stocking ponds (over 4,000 crayfish under 15 g per pond).

In the most productive pond, the juvenile recruitment was calculated as nearly 140 offspring per female per season. The efficiency of recovery of nursed juveniles per female for that particular pond was only approximately 10%. This estimation is based on the fact that *C. quadricarinatus* females are known to breed 2-3 times per year under laboratory conditions in Israel (Barki et al., 1997), and are expected to produce about 450 eggs per clutch on the basis of the linear relationship of clutch size to female fresh weight (King, 1993) and female mean size during the second growout season. Similar, but slightly improved, results due to periodic juvenile collection were reported by Rouse (1995). The low efficiency of recovery of nursed juveniles from breeding ponds (i.e., mixed sex stocking) reported in the present study could be improved by selective harvest of the young throughout the growout season, and the addition of appropriate shelters similar to the extensive method used for the production of juveniles in Australia (Ackefors, 1994).

The procedure of growing *C. quadricarinatus* in monosex populations for a second growout season does indeed seem feasible. However, many issues still remain problematic in terms of the evaluation of economic profitability. The effects of selective harvesting of very large individuals are not known, and the effects of density have been investigated only for the first growout season (Pinto and Rouse, 1996). Prices for very large redclaw crayfish are not known, although a preliminary market assessment in Sweden has indicated at least a 30% premium for 100 g individuals as compared with 40-50 g crayfish (Harpaz, personal communication). Development of a technology for the formation of monosex populations, and a detailed investigation of the overwintering phase in terms of survival rates and cost effectiveness, are thus required.

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