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PRODUCTION OF *MACROBRACHIUM ROSENBERGII* IN MONOSEX POPULATIONS: YIELD CHARACTERISTICS UNDER INTENSIVE MONOCULTURE CONDITIONS IN CAGES

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ABSTRACT

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The production of *Macrobrachium rosenbergii* monosex populations was examined under intensive growth conditions in cages. It was found that an all-male population yielded 473 g/m² within 150 days, whereas an all-female population and a mixed population produced 248 g/m² and 260 g/m², respectively, during the same growout period. Since the performance of the mixed population in cages is comparable to that of a normal typical juvenile population in commercial earthen ponds, with an average production of 2500—3000 kg/ha, it appears possible to obtain a yield of 4700 kg/ha within 150 days from all-male populations grown under intensive monoculture conditions.

A comparison of growth performance of each of the sexes when raised alone and when raised in mixed populations showed that whereas females are strongly affected by the presence of males, resulting in growth inhibition, males are hardly influenced by the presence of females.

The findings of this study call for intensive efforts in research directed towards the controlled establishment of prawn monosex populations.

INTRODUCTION

The separation of animal populations according to sex is a basic procedure in livestock husbandry. Production techniques, based on monosex subpopulations, have been applied for many years in the poultry industry, in cattle rearing, as well as in the culture of other domesticated animals. Monosex production strategy is successfully applied to aquaculture as well, in the intensive production of *Tilapia* spp. (Mires, 1977; Taymen and Shelton, 1978).

Differences between males and females of the same organism, e.g. growth rate, alimentary needs and behavioral patterns, and the nature of the target

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agricultural product, e.g. flesh, milk, eggs, dictate the need to establish management systems specifically adjusted to one or the other of the sexes. Since a monosex culture is non-breeding, energy is diverted to growth while reproduction is carried out in separate, controlled systems.

During the process of the domestication of the freshwater prawn, *Macrobrachium rosenbergii*, a major difference in growth strategy of the males and of the females became apparent and has recently been well characterized and documented (Smith et al., 1978; Brody et al., 1980; Cohen et al., 1981).

In a typical pond culture, during a 6-months growout period of a single age population, females demonstrate a relatively uniform growth rate, resulting in a homogeneous size distribution with a weight range of 20—35 g. Males, on the other hand, vary greatly in their expressed growth rates and show a wide, positively skewed size distribution. A careful examination of the male population reveals three distinct morphotypes which represent three stages in male development: (a) small males (SM): about 50% of the male population, presented in the peak of the male distribution curve in a weight range of 1—10 g, (b) orange claw males (OC): comprise about 40% of the males and have a wide weight range of 10—50 g, and (c) blue claw males (BC): the remaining 10% which are the largest of the males, reaching up to 70 g. Whereas the weight range of each morphotype, except for that of the SM, is strongly affected by culture conditions, the hierarchy among the males remains unchanged. This hierarchy is closely associated with social roles and reproductive activities (Ra'anan and Cohen, 1985). SM and BC males actively participate in mating and fertilization, investing little energy in somatic growth, while OC males are characterized by a fast growth rate and reduced reproductive activity (Sagi, 1984; Ra'anan and Sagi, 1985).

This difference between male and female growth strategy strongly influences the marketable yield. With a minimum market size of 30 g, about 50—60% of the males and 25—35% of the females would remain below market size at the end of the 6-months growout period typical of the temperate region. In order to overcome this problem, a selective harvest procedure was introduced (Cohen et al., 1983b; Ra'anan and Cohen, 1983). It was found that a periodic selective removal of the larger males (OC, BC) throughout the growout season results in the SM males promptly transforming into OC males and shifting into the rapid growth pattern, thus significantly improving the percentage of marketable males by the end of the period. Females, on the other hand, are far less affected by such selective harvests. Their final weight is strongly dependent on the size at which they reach sexual maturation, which is, in turn, a function of density and other environmental factors (personal observations).

On the basis of the observed differences in growth patterns between males and females when reared together, it became of interest to examine the growth patterns and yield characters of each of the sexes when raised separately. The purpose of the present study was to examine these parameters in monosex populations compared with mixed populations, both reared under intensive growth conditions.

MATERIALS AND METHODS

Source of the animals

Post-larvae were obtained from the hatchery operated by Aquaculture Production Technology (Israel) Ltd., and nursed in the Nir David fish farm. All prawns were derived from a single hatching cycle, and were then nursed in a super-intensive primary nursery from mid-November until the end of January (Ra'anan and Cohen, 1982). Nursed juveniles were then transferred into a larger earthen pond supplied with geothermal water (26°C) for secondary nursing until the beginning of June. At this stage, juveniles averaged 6.57 g, and the separation of males from females was easily performed.

Experimental design and management procedures

The experiment included three treatments: (a) an all-male population; (b) an all-female population; and (c) a control, mixed population with a male to female ratio of 1:1. Each treatment was examined in five replicates. Each replicate included 40 individuals stocked in a net cage of 2 m^3 (1 × 1 × 2 m). Each cage included substrates to increase the surface area by 30 m^2 and to provide shelter (Ra'anan et al., 1984). The cages were placed randomly in a concrete bottomed, plastic-covered greenhouse pond. Water temperature was kept at 24—28°C throughout the entire period, and the pond was aerated 24 h a day (using a blower and air stones). Water quality, evaluated by levels of ammonia and nitrate, was examined weekly. The water had a rich natural productivity (including insect larvae, *Daphnia*, *Moina*, etc.), encouraged by an occasional application of fresh chicken manure. In addition, supplemental food in the form of fish pellets (30% protein) was applied to each of the cages daily.

Measurements and data collection

Each prawn was sexed and weighed at stocking. This procedure was repeated once a month thereafter, until the end of the experiment, altogether five measurements.

During the measurement procedure, the state of sexual maturation of each female was recorded according to three main categories: (a) virgin females (without an apparent brood chamber), (b) females carrying eggs (ovigerous), and (c) females with an enlarged brood chamber (previously ovigerous). For each of the above categories, the state of gonadal development was also examined, as an additional indication of status of sexual maturation and intensity of reproductive activity (Sagi and Ra'anan, 1985). Males were categorized according to their morphological appearance into blue claw males (BC), orange claw males (OC), small males (SM), and undefined males (mainly individuals with missing or regenerating claws).

Once every 2 weeks, selective harvests were performed. Prawns weighing 30 g or more and males reaching the BC phase, were removed and recorded as marketable yield. Such selective harvests were performed altogether nine times. Each individual removed was sexed, weighed, and characterized according to the above-mentioned categories.

Upon the completion of the experiment, performance under the three treatments was analyzed with regard to marketable yields, submarket-size prawns, and population structure. Special attention was given to a comparison of male and female growth performance in the monosex treatments with that in the mixed population treatment.

Statistical analysis

Marketable and submarket average yields for the three treatments at each 2-week interval were examined graphically. Standard errors were derived from the variation among the five replicates of each treatment. Since the number of prawns of each sex stocked in the monosex treatments was double the number of individuals of that sex stocked in the mixed population, it was impossible to compare final biomass produced in the various treatments. In order to overcome this problem, we used the relative total weight (RTW), computed according to:

RTW = Cumulative biomass at time, t/Initial biomass

The statistical significance of the differences between the RTW values was assessed by a standard t-test. All averages presented are accompanied by the standard error of mean.

The difference in the reproductive state of females and the corresponding difference in the morphotypic appearance of males between the monosex and the mixed populations were assessed by a χ^2 test. The source of the observed differences was identified by using a simultaneous test procedure which examined all the 2×2 tables obtained by collapsing the reproductive and morphotypic categories (Gilula and Krieger, 1983).

RESULTS

Yield characteristics

The total cumulative biomass of marketable size prawns (> 30 g) was compared among the three treatments (Table 1). While the all-male population yielded 945 g per cage (= 472 g/m^2), the all-female and the mixed population produced 496 g per cage and 521 g per cage (248 g/m^2 and 260 g/m^2), respectively. Thus, the production of all-males exceeded by more than 80% that of the other two treatments, which did not differ significantly from one another.

TABLE 1

Yield characteristics at the end of the growing season[a]

	All-male population	All-female population	Mixed population
Characterization of marketable yield (⩾ 30 g)			
Total wt. (g/2 m²)	945.03 ± 43.87^{A}	496.22 ± 41.88^{B}	521.47 ± 44.56^{B}
Av. wt. (g)	33.74 ± 0.25^{A}	31.35 ± 0.13^{B}	32.52 ± 0.34^{C}
No. of prawns	28.00 ± 1.28^{A}	15.8 ± 1.3^{B}	16.00 ± 1.35^{B}
% of prawns	(70.00 ± 3.2)	(39.5 ± 3.25)	(40.00 ± 3.38)
Characterization of submarket yield (< 30 g)			
Total wt. (g/2 m²)	57.00 ± 15.6^{A}	491.72 ± 36.61^{B}	423.44 ± 42.25^{B}
Av. wt. (g)	22.45 ± 1.31^{AB}	26.34 ± 0.28^{A}	23.23 ± 0.59^{B}
No. of prawns	2.6 ± 0.69^{A}	18.8 ± 1.37^{B}	18.4 ± 1.38^{B}
% of prawns	(6.5 ± 1.7)	(47.00 ± 3.42)	(46.00 ± 3.45)
Total survival rate			
No. of prawns	30.6 ± 1.19^{A}	34.6 ± 0.96^{B}	34.4 ± 0.98^{B}
% of prawns	(76.5 ± 2.98)	(86.5 ± 2.4)	(86.00 ± 2.45)

[a]Index letters indicate statistical significance of difference between treatments within each line. Values bearing the same index letter do not show a significant difference (t-test).

The average weight of the marketable prawns was also significantly higher for the all-male population, when compared with the all-female population and the mixed population, 33.7 g, 31.4 g, 32.5 g, respectively (two-tailed P value $\leqslant 0.004$). Seventy per cent of the males stocked alone reached market size within the limited growout period of 152 days. In contrast, of the prawns raised in the all-female and in the mixed populations, only 39.5% and 40%, respectively, became marketable during the same period.

The remaining biomass of submarket size prawns (< 30 g) in the all-male group comprised only 57 g per cage (= 28.5 g/m²), averaging 22.45 g each, and represented 6.5% of the prawns initially stocked. At the same time, the total submarket size biomass of the all-female population was 492 g per cage (246 g/m²), representing 47% of the females initially stocked. These remaining small females formed a highly homogeneous group, significantly larger than that of the males ($P < 0.01$), with prawns averaging 26.34 g each.

It should be noted that out of the total biomass produced in each of the three stocking treatments, 94.3% of the male biomass was marketable, while in the cases of the all-female and the mixed populations only 50.2% and 55.1%, respectively, of the total weight produced could be marketed. The overall survival rate was significantly lower in the all-male treatment, only 76.5% as compared with 86.5% and 86% for the all-female and the mixed groups, respectively (two-tailed P value $\leqslant 0.005$).

Fig. 1 shows the rate of accumulation of the marketable yield as a result of selective harvests throughout the experimental period. It can be clearly seen that prawns of the all-male group reached 30 g and above at a much faster rate than individuals in the all-female group. After 80 days of growout, while the all-female population only began to produce market-size prawns, about 40% of the all-male yield was already harvested. The total biomass produced in the all-female and in the mixed population treatments after 152 days growout, was reached by the males as early as 95 days after stocking.

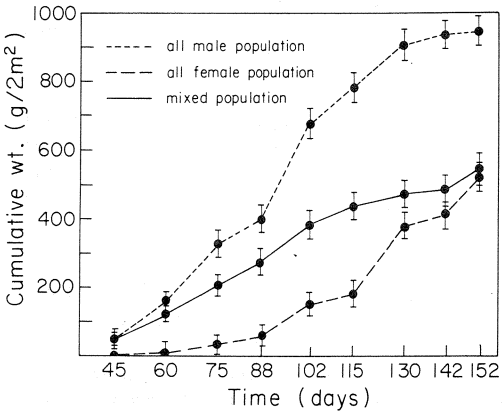

Fig. 1. Cumulative weight of marketable prawns (⩾ 30 g) obtained by selective harvests.

Female growth performance in the all-female and mixed populations

A comparison between the yield of females when reared alone and when grown together with males is presented in Table 2. The marketable biomass, expressed in terms of the relative total weight (RTW), of the all-female population was significantly higher than that of the females in the mixed population, 1.95 vs. 0.73 (two-tailed P value $\leqslant 0.01$). Although the biomass of the females in both treatments increased by the same factor, namely 3.8-fold, the distribution of the biomass between market and submarket size was extremely different. Whereas the total biomass produced by the all-female group was almost equally divided between market and submarket prawns, 51.1% and 48.9%, respectively, the females in the mixed population produced only 18.9% marketable biomass, while 8.1% of the yield remained at submarket size. These differences were brought about by the significantly higher percentage of individuals which reached the 30 g size in the all-female group, 39.5% vs. 14% of the females in the mixed population (two-tailed P value $\leqslant 0.025$).

An analysis of the biomass produced in both female populations reveals a significant difference in the distribution of prawns among the different reproductive states in both market size ($\chi^2 = 44.75$, $P = 0.000$), as well as

TABLE 2

Characterization of female growth in the monosex and in the mixed population

	All-female population		Females in mixed population	
	Marketable yield (⩾ 30 g)	Submarket yield (< 30 g)	Marketable yield (⩾ 30 g)	Submarket yield (< 30 g)
Relative total weight (RTW)[a]	1.95 ± 0.38	1.87 ± 0.15	0.73 ± 0.25	3.13 ± 0.22
% of total biomass	51.1%	48.9%	18.9%	81.1%
Av. wt. (g)	31.35 ± 0.13	26.34 ± 0.28	31.46 ± 0.23	24.96 ± 0.33
% of females originally stocked	39.5 ± 3.2	47.3 ± 3.4	14.0 ± 3.3	75.0 ± 4.1
Maturation status[b]				
Immature				
No. (%)	11 (13.9)	8 (8.5)	2 (11.3)	—
Developing gonads				
No. (%)	38 (48.1)	25 (26.6)	1 (7.14)	21 (28)
Berried				
No. (%)	2 (2.5)	—	9 (64.3)	19 (25.3)
Mature but inactive				
No. (%)	28 (34.4)	61 (64.9)	2 (14.8)	35 (46.7)
Total female survival	86.5 ± 2.4		89.0 ± 3.1	

[a]RTW = Cumulative weight/Initial biomass stocked.
[b]Statistical analysis of differences in the distribution of maturation status of females between monosex and mixed populations was performed according to χ^2 contingency table; see details in text.

submarket size individuals (χ^2 = 32.67, P = 0.000). The difference in both size groups is attributed to a significantly higher proportion of berried females found amongst the females in the mixed population ($P \leqslant 0.0$).

The rate of increase of the RTW throughout the growout period for males and females reared separately and mixed (Fig. 2) indicates that females in the monosex population reached marketable size toward the end of the production period, within the last 37 days. During this period, females in the mixed population were producing market-size prawns at a very low rate.

Male growth performance in the all-male and mixed populations

A comparison of yield characters of the males in the all-male stocking vs. the males in the mixed population is presented in Table 3.

The difference in biomass gain (expressed by RTW) between the market and the submarket size yields in the all-male population (3.39 vs. 0.21) was very similar to that obsdrved in the mixed population (3.34 vs. 0.42). In both populations about 90% of the biomass was comprised of prawns weighing 30 g and over. However, the average weights of both marketable and sub-

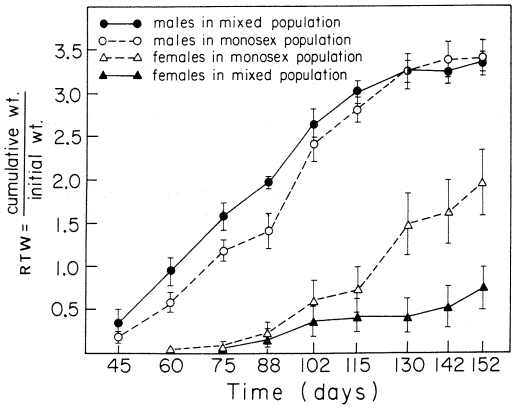

Fig. 2. Cumulative biomass of harvested prawns — breakdown by sex.

TABLE 3

Characterization of male growth in the monosex and in the mixed population

	All-male population		Males in mixed population	
	Marketable yield (⩾ 30 g)	Submarket yield (< 30 g)	Marketable yield (⩾ 30 g)	Submarket yield (< 30 g)
Relative total weight (RTW)[a]	3.39 ± 0.12	0.21 ± 0.06	3.34 ± 0.19	0.42 ± 0.15
% of total male biomass produced	94.2	5.8	88.8	11.2
Av. wt. (g)	33.74 ± 0.25	22.45 ± 1.31	32.75 ± 0.40	14.30 ± 2.02
% of males originally stocked	70.0 ± 3.2	6.50 ± 1.70	66.0 ± 4.6	3.40 ± 0.73
Morphotypes[b]				
BC males				
No. (%)	8 (5.7)	—	14 (21.2)	—
OC males				
No. (%)	108 (77.1)	7 (53.8)	42 (63.6)	3 (17.6)
Small males				
No. (%)	—	—	—	11 (64.7)
Other				
No. (%)	24 (17.2)	6 (46.2)	10 (15.2)	3 (17.7)
Total male survival	76.5 ± 3.0		83.0 ± 3.6	

[a]RTW = Cumulative weight/Initial biomass stocked.
[b]Statistical analysis of differences in the distribution of morphotypes between monosex and mixed populations was performed according to χ^2 contingency table; details in text.

market size prawns in the all-male stocking were significantly higher than those obtained in the mixed population (t-test, $P < 0.025$).

The distribution of male morphotypes in both market and submarket yields differs significantly between the all-male group and the males in the mixed population ($\chi^2 = 11.32$, $P = 0.0035$ and $\chi^2 = 13.3$, $P = 0.0013$, for marketable and submarket size prawns, respectively). The different frequency distribution of morphotypes is attributed to the fact that in the mixed population, there are significantly more BC males among the marketable prawns ($P \leqslant 0.01$), and significantly more small males among the submarket prawns ($P \leqslant 0.01$), compared with the all-male stocking. The rate of increase in the marketable biomass (Fig. 2) was quite similar in both male groups throughout most of the growing season.

DISCUSSION

The highest marketable yield of 473 g/m^2 was obtained in the all-male stocking, while the all-female and mixed populations produced yields of 248 g/m^2 and 260 g/m^2, respectively. Prawn yields previously obtained in earthen ponds stocked with typical, unseparated juvenile populations, reached levels of 2500–3000 kg/ha (Cohen et al., 1983b), similar to the yields produced by the mixed population in the present cage study. By extrapolation, it can be speculated that by intensive culturing of all-male populations in earthen ponds, a production rate as high as 4700 kg/ha can be expected. Furthermore, examination of the rate of accumulation of marketable biomass in the all-male group (Fig. 1) reveals a plateau during the last 20 days, resulting from the fact that hardly any males had remained in the cages by this stage. This observation suggests that in the case of all-male monoculture, a growout period of only 130 days may prove sufficient, thus allowing 2.7 production cycles per year in the tropics and an annual yield of about 12.9 tons/ha!

An analysis of the morphotypic differentiation of marketable prawns obtained from the all-male group, reveals that the yield was comprised mostly of OC males and of very few BC males. Since the OC males represent the fast-growing stage and the BC males have reached a terminal state with respect to further growth (Ra'anan and Cohen, 1985; Ra'anan and Sagi, 1985), it appears that most of the harvested prawns were still in the period of rapid growth. Hence, higher biomass could be obtained in the all-male stocking by increasing the minimum market size and adjusting the frequency of selective harvests accordingly.

A comparison of growth performance between males in the all-male group and males in the mixed population shows that the presence of females has very little effect on the growth of males. The higher frequency of small males in the latter stocking might be due to the relatively higher density as compared with that of the all-male stocking. This may have resulted from the fact that the females in the mixed group were extremely slow to reach market size, and therefore were not selectively harvested, and that the sur-

vival rate in the mixed group was higher. Alternatively, it is possible that the presence of females resulted in a larger fraction of males remaining small due to the biological advantage of small males in reproduction (Ra'anan and Sagi, 1985). The mechanism required for such signals is unknown at present.

The all-female group produced yields similar to those reached by the mixed population (Fig. 1). A comparison of the growth performance of females when stocked alone or in the presence of males shows that, contrary to the males, the females are strongly affected by the presence of the opposite sex. An analysis of the state of maturation of the females reveals that, although the percentage of sexually mature females did not differ significantly between the two treatments, the percentage of berried females, of both market and submarket-size, was much higher in the mixed group. This finding is probably due to the fact that berried females invest energy in caring for the eggs for a period of 21 days, while the unfertilized females drop the eggs within 24—48 h from laying (Ling, 1969).

The improved growth rate of the all-female group was achieved in spite of the higher density conditions of this group. (Earlier selective harvesting of males reduced density in the mixed population.) Moreover, examination of the harvested females from the mixed stocking reveals that the egg biomass comprises over 11% of the total body weight of the berried females (Chaw and Liao, 1977). Thus, it can be concluded that 64% of the females which were considered to have reached the market size of 30 g were actually below market size, since the eggs are not edible and, in many cases, are washed off the female's abdomen prior to marketing (personal knowledge).

From the aquaculturist's point of view, culturing all-female prawn populations might be advantageous where periodic selective harvests are not feasible and a uniform size final product is desired. Such production systems may include polyculture with fish in large ponds (Cohen et al., 1983a). On the other hand, the all-male populations present a great potential for the production of prawns in relatively small water bodies under very intensive conditions with periodic selective harvests, which ensure a unuform product over an extended marketing period.

Based on these findings, it seems that the establishment of monosex prawn populations under controlled conditions is an essential direction for further research aiming at economical improvement of *M. rosenbergii* aquaculture.

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