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A standardized comparison of semi-intensive pond culture of freshwater prawns *Macrobrachium rosenbergii* at different latitudes: production increases associated with lower water temperatures

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Abstract

This study was conducted to evaluate the effects of different ambient water temperatures on growth and population structure of freshwater prawns raised under standardized culture conditions. Juvenile prawns averaging 0.26 ± 0.14 g were stocked into seven 0.04 ha ponds at two study sites. Three ponds were located in Kentucky (KSU:latitude 38°12′) with seasonal water temperatures averaging 24–26°C. Four ponds were located in Mississippi (MSU:latitude 33°28′) with a seasonal average of approximately 30°C. Prawn stocking, sampling, and harvest dates were identical at both locations. Juvenile prawns were single source and were harvested from the same nursery tank for stocking at both locations. The diet used at both sites was from a single production run and was stored under refrigerated conditions. Prawns at both sites were fed twice daily according to a computer generated feeding schedule. Beginning approximately 8 weeks prior to harvest, sampled prawns were also individually identified according to sexual morphotype. At harvest (117 days after stocking) all prawns at both sites were counted, morphotyped, and weighed. Prawn weights were higher at the more northerly site at all samples after 42 days post-stocking. When sampled 64 days post-stocking (5 August) no sexually mature male or females were found. Mature morphotypes were first captured in the Day 83 sampling (25 August). In the Day 106 sampling (16 September), there were no significant differences ($P > 0.05$) in numbers or weights of the three male morphotypes between sites. However, among females there were significantly fewer

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($P \leq 0.01$) berried females at KSU with their average weights being significantly greater ($P \leq 0.05$) than those at MSU (35 g and 31 g, respectively). At harvest (Day 117: 27 September) KSU had significantly ($P \leq 0.05$) fewer berried females (32%) and more virgins (45%) than MSU (56% and 25%, respectively). Berried females at KSU weighed significantly more than at MSU (33 g and 26 g, respectively). There were no statistically significant differences ($P > 0.05$) between the two sites in prawn survival (83%), average weight (35 g), and feed conversion (2.3). Production was significantly greater ($P \leq 0.01$) at KSU (1261 kg ha^{-1}) than MSU (1091 kg ha^{-1}) largely reflecting higher average weights of some morphotypes and slightly higher survivals. Differences in proportions and sizes of female morphotypes probably indicate delayed sexual maturation at the more northerly site, prolonging somatic growth which normally ceases when food energies are redirected to reproductive activities.

Keywords: Pond culture; *Macrobrachium rosenbergii*; Latitude; Temperature

1. Introduction

Temperatures of 26–31°C are considered satisfactory for prawn growth (Sandifer and Smith, 1985) with 29–31°C considered optimal (New, 1990). However, most studies on temperature tolerances and requirements are conducted on larval stage animals (Farmanfarmaian and Moore, 1978). Larger animals may respond differently to culture temperatures (Silverthorn and Reese, 1978). Data on the quantitative relationship between water temperature and juvenile or adult growth and production of prawns are lacking (Malecha, 1983). Tidwell et al. (1994) reported that prawns cultured in ponds with water temperatures averaging 25°C had higher production rates (11.5 kg ha^{-1} day^{-1}) than those reported by D'Abramo et al. (1989) for prawns cultured at 29°C (5.5–5.9 kg ha^{-1} day^{-1}). Both studies were conducted under similar conditions of stocking size, density, and diet. Buck et al. (1981) reported that prawns raised in Illinois had production rates of 6.7 kg ha^{-1} day^{-1}, despite water temperatures exceeding 27°C and 24°C for only 22 days and 68 days, respectively.

Effects of reduced temperatures on population structures or aggressive interaction within prawn populations could be complete or partial explanations. The freshwater prawn (*Macrobrachium rosenbergii*) exhibits a complex population structure composed of three male morphotypes: small males (SM), orange-claw males (OC), and blue-clawed males (BC), and three female morphotypes: virgin (VR), berried-females (BR), and open-females (OP) (Cohen et al., 1981). This population structure has been shown to be influenced by stocking density (Karplus et al., 1986), age at stocking (Hulata et al., 1990), nutrition (MacLean et al., 1989) and size grading prior to stocking (Daniels and D'Abramo, 1994). Tidwell et al. (1994), reported that prawns cultured under coolwater conditions had a population structure that differed from those cultured at higher water temperatures. These lower culture temperatures appeared to increase both total production and the percentage of market-size prawns. However, direct comparisons between studies remained impossible due to differences in stocking rates, stocking sizes, genetics of seedstock, diets, feed rates, and possibly other factors (Tidwell et al., 1994). In order to establish unequivocally the role of culture temperature the present study was designed to evaluate growth, survival, and population characteristics of prawns raised at different latitudes under standardized culture conditions.

2. Materials and methods

2.1. Description, preparation, and stocking of ponds

Seven ponds at two study sites were used in the investigation. Three ponds located at the Aquaculture Research Center, Kentucky State University (KSU) in Frankfort, KY, represented the higher latitude location (latitude 38°12′). Summer water temperatures of research ponds in this area average 24–26°C (Tidwell et al., 1993; Tidwell et al., 1994). The other four ponds were located approximately 500 miles south (latitude 33°28′) at the Mississippi State University (MSU) Aquaculture Unit of the Mississippi Agricultural and Forestry Experiment Station, Starkville, MI. Water temperatures of research ponds in previous prawn studies at this location have averaged approximately 30°C (D'Abramo et al., 1989).

Surface area of all experimental ponds was 0.04 ha and average water depth was approximately 1.1 m. Less than 1 week prior to the anticipated stocking date, ponds at both sites were filled and treated with one application of liquid fertilizer (10:34:0) at an initial rate of 9.0 kg ha^{-1} of phosphorous to achieve an algal bloom. One 1/2 hp vertical pump aerator operated continuously in each pond to prevent thermal stratification. Water temperatures and dissolved oxygen concentrations were determined in all ponds twice daily at approximately 9.00 h and 15.30 h over the deepest part of the pond. Readings were taken approximately 0.5 m below the surface using a YSI Model 57 oxygen meter (Yellow Springs Instruments, Yellow Springs, OH). The pH of each pond was determined daily at 15.30 h using an electronic pH meter (Hannah Instruments, Ltd., Mauritius).

Juvenile prawns for stocking at both locations were produced under hatchery and nursery conditions at MSU and were harvested from the same culture tank. Prawns used in Kentucky were transported by truck in a live-haul tank supplied with pure oxygen and agitators on 1 June, 1994 and held overnight in two 3000 liter fiberglass tanks, partially filled with plastic netting to provide substrate. Prawns were stocked at both facilities on the same day (2 June, 1994). On the stocking date the mean stocking weight was determined from a sample of 100 prawns that were lightly blotted to remove surface water and individually weighed (mean $\pm$ SD $= 0.26 \pm 0.14$ g). Prawns were hand-counted and stocked in each pond at a density of 4 m^{-2}.

2.2. Samples

A 3.2 mm square mesh seine was used to collect a sample of > 50 individuals from each pond every 3 weeks during the growing season. Prawns composing the sample were counted, group weighed (wet weight) to the nearest gram, and returned to their respective pond. Sampling procedures were conducted on the same dates at both facilities. Beginning approximately 50 days prior to harvest, with the 5 August sampling, captured prawns were individually weighed, morphotyped as described by Daniels and D'Abramo (1994) and returned to the pond. This date was intended to precede the occurrence of sexually mature morphotypes so that subsequent samples should document the timing of morphotype development and development of population structure at the two locations.

2.3. Feed and feeding rates

The formulation of the diet used was the same as presented for Diet 2 in Tidwell et al. (1993) and the diet contained approximately 32% protein. Dietary ingredients were processed into 5 mm sinking pellets by a commercial feed mill (Farmers Feed Mill, Lexington, KY). After bagging, one-half of the diet was shipped to the Mississippi research site by truck. Feeds were stored under refrigerated conditions at both facilities until use.

Two separate feedings, each consisting of one-half of the total daily ration, were distributed over the entire surface of each pond between 09.00 h and 10.00 h and between 15.00 h and 16.00 h. Prawns in each pond were fed at a rate of 25 kg ha^{-1} day^{-1} until an average individual weight of 5 g was achieved. At sizes > 5 g prawns were fed according to a computer generated feeding schedule based upon a percentage of their body weight, an assumed 1% $week^{-1}$ mortality, and a 2.5 feed conversion ratio (FCR), as described by Daniels and D'Abramo (1994). Every 3 weeks, total prawn biomass in each pond was calculated from sample weights and feeding rates were adjusted accordingly.

2.4. Harvest

Harvest at both sites occurred after 117 days of culture. One day prior to harvest, the water level in each pond was lowered to approximately 0.9 m at the drain end. Each pond was seined (beginning 26 September 1994) two or three times using a 1.3 cm square mesh seine. Complete draining of each pond followed and all remaining prawns were manually harvested from the bottom and transferred to clean water for purging. Total weight and number of prawns from each pond were recorded. At KSU each prawn was individually weighed and morphotyped as described in Tidwell et al. (1993). At MSU prawns were sorted by morphotype then all prawns within each morphotype were counted and collectively weighed. Morphotype classifications included three female morphotypes, berried (egg-carrying; BE), open (previously egg-carrying; OP), and virgin (VG), or one of three male morphotypes, blue-claw (BC), orange-claw (OC), and small (< 20 g; SM), as described by Daniels and D'Abramo (1994). This classification system was followed so that a direct comparison with data from previous years would be possible.

2.5. Statistical analysis

Growth performance was measured by mean individual prawn wet weight (g), total yield (kg ha^{-1}), daily yield (kg ha^{-1} day^{-1}), survival (%), and feed conversion. Population structures were evaluated by the average weight and proportion (by number) of each morphotype in the population. Water temperatures at the two sites for the duration of the pond culture period were also evaluated in terms of degree-days greater than 20° (DD20), obtained by subtracting 20 from afternoon water temperature (Tackett et al., 1987). The cumulative DD20 value for each site was compared with prawn sample data using correlation and regression analyses (Neter and Wasserman, 1974;

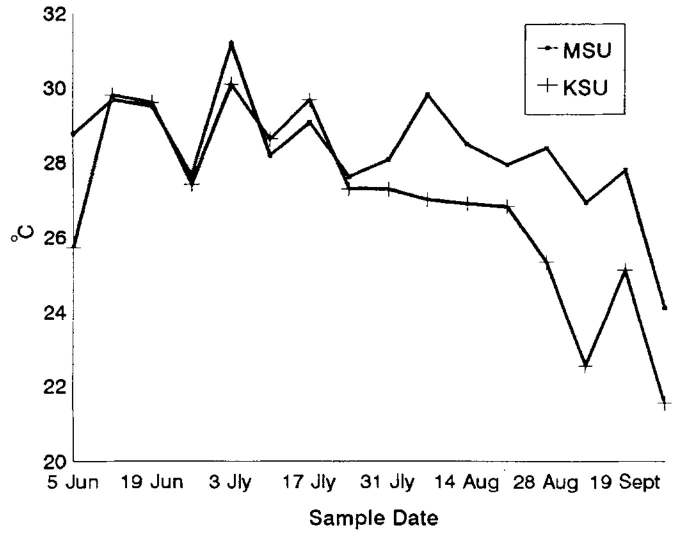

Fig. 1. Average weekly afternoon temperatures at two study locations. Temperature in each pond (three at KSU, four at MSU) was measured daily so that each point represents 21 measurements at KSU and 28 measurements at MSU.

Snedecor and Cochran, 1980). Data from the two study sites were compared using Student's *t*-test (Microstat, 1984). Percentage data were arcsin transformed prior to analysis (Zar, 1984).

3. Results

Average weekly afternoon water temperatures for the two study sites during the 117 day culture period are presented in Fig. 1. The overall mean for the Kentucky State University (KSU) and Mississippi State University (MSU) sites were 26.9° and 28.0°, respectively (Table 1). For the duration of the culture period cumulative degree days greater than 20°C (DD20) totaled 889 DD20s at KSU (three pond average) and 1060 at

Table 1
Overall means (± SE) of daily morning and afternoon water temperatures and dissolved oxygen concentrations and afternoon pH determinations in ponds located at different latitudes. Ponds at KSU were approximately 500 miles north of MSU. Treatments were replicated in triplicate ponds at KSU and quadruplicate ponds at MSU

Variable	Study site KSU	MSU
a.m. Temp (°C)	25.0 ± 2.6	26.4 ± 2.0
p.m. Temp (°C)	26.9 ± 2.7	28.0 ± 2.1
a.m. DO (mg l^{-1})	7.2 ± 0.8	7.2 ± 0.1
p.m. DO (mg l^{-1})	9.8 ± 1.4	9.1 ± 0.6
pH	8.9 ± 0.3	8.1 ± 0.1

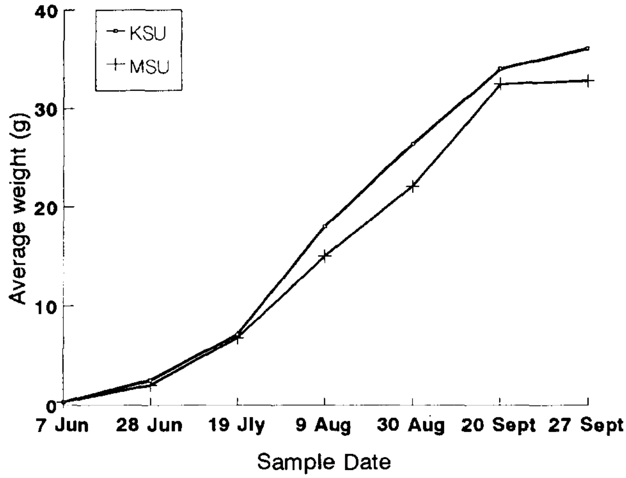

Fig. 2. Mean sample weights of prawns sampled triweekly from earthen ponds at two study locations. Each data point at KSU represents three ponds and MSU represents four ponds.

MSU (four pond average). Overall means for morning water temperature, morning and afternoon dissolved oxygen (DO), and afternoon pH recorded at both locations during the culture period are presented in Table 1.

Sample weights of prawns raised at the two locations are presented in Fig. 2. After Week 6 (19 July), prawn weights at the KSU site were consistently higher than those at the MSU site, though differences were not statistically significant ($P > 0.05$).

3.1. 5 August sampling

At the 5 August sampling, when morphotypes were first identified, there were no significant differences ($P > 0.05$) in either numbers or average weights of the six morphotypes between the two locations. Captured females at both locations were 100% virgins (Fig. 3) and averaged approximately 16.5 g in weight. Approximately 39% of males had progressed from SM to OC status (Fig. 4), but no males had achieved BC status.

3.2. 25 August sampling

In the 25 August samples a significantly smaller ($P < 0.05$) percentage of males at KSU were SM (23.9%) compared with that of MSU (48.5%) (Fig. 4). The percentage of males classified as OC was higher at KSU (71.1%) than at MSU (50.7%) but this difference was not statistically significant ($P > 0.05$) due to high within-treatment variation. During the three weeks since the previous sampling 4.9% and 7.4% of the female prawns had achieved egg-bearing status at the KSU and MSU sites, respectively (Fig. 3). A small percentage of males (< 1.5%) had progressed to BC at both locations (Fig. 4). Average weights of BC males were higher at KSU than MSU (Fig. 5) and this

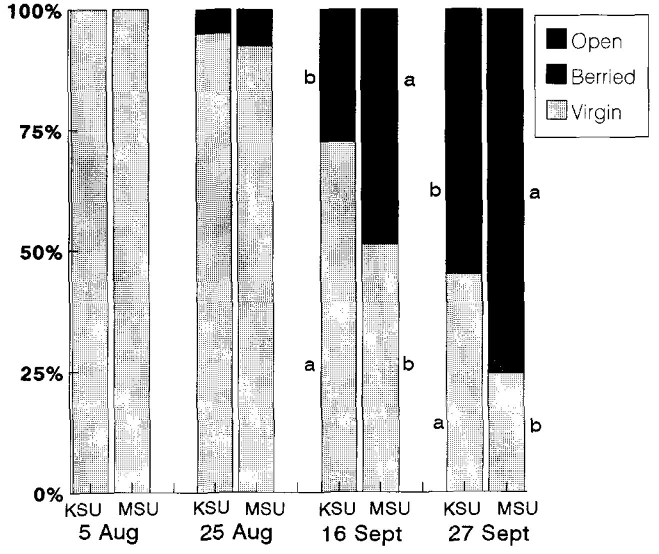

Fig. 3. Proportions of female morphotypes as a percent of total females at the two study sites on three sampling dates and final harvest (27 September). For each morphotype, proportions at the two study sites followed by different letters within sample dates were significantly different ($P < 0.05$).

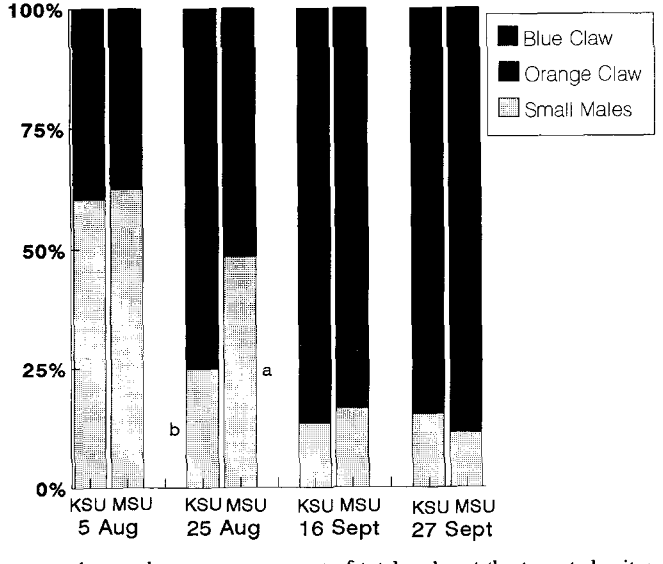

Fig. 4. Propor..ons of male morphotypes as a percent of total males at the two study sites on three sampling dates and final harvest (27 September). For each morphotype, proportions at the two study sites within sample dates were significantly different ($P < 0.05$).

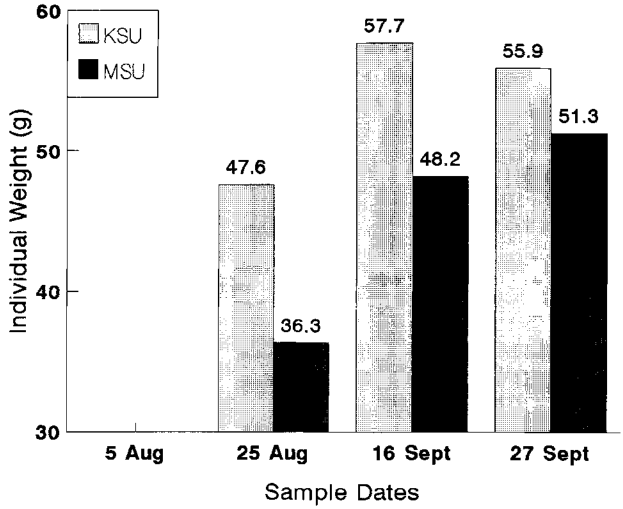

Fig. 5. Average individual weights (g) of blue claw males at two study sites on three sample dates and final harvest (27 September). There were no significant differences between study sites within sample dates ($P > 0.05$).

relationship continued for the next two sampling dates (16 September and 27 September); however these weight differences were not significantly different ($P > 0.05$). Average weights of the other five morphotypes at the KSU and MSU sites were also not significantly different ($P > 0.05$) for the 25 August sampling.

3.3. 16 September sampling

At the 16 September sampling, no significant differences ($P > 0.05$) in proportions of males classified as SM, OC, or BC were found (Fig. 4). However, during the interval between the 25 August and 16 September sample dates, large differences in the composition of female populations developed between the study sites. At the 16 September sampling there were significantly fewer ($P \leq 0.01$) BR and OP females at KSU than MSU (Fig. 3). In addition, the average weight of BR females at KSU (35.2 g) was significantly greater ($P \leq 0.05$) than those at MSU (31.0 g) (Fig. 6). Also, there were significantly more ($P \leq 0.05$) VR females at KSU than at MSU (72.3% and 51.2%, respectively) (Fig. 3).

3.4. 27 September: final harvest

At final harvest (27 September) there was no significant difference ($P > 0.05$) between sites in the proportional composition of the three male morphotypes (Fig. 4) or their average weights (Fig. 3). Omission of data from the one replicate at MSU that had low survival (66%) resulted in the average weight of BC males at KSU (56 g) being significantly greater ($P \leq 0.01$) than at MSU (50 g).

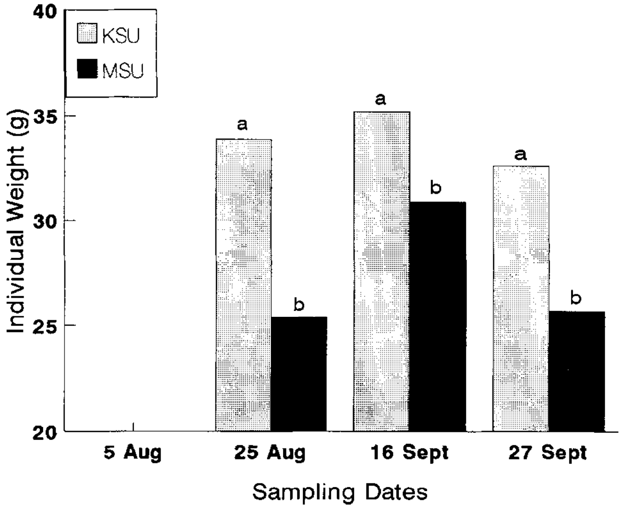

Fig. 6. Average individual weights (g) of berried females at two study sites on three sample dates and final harvest (27 September). Different letters within sample dates indicate significant differences ($P < 0.05$) between locations.

Large differences in female population structure between the two sites were again observed. The proportion of BR females at MSU (56%) was significantly greater ($P \leq 0.01$) than that at KSU (32%). Correspondingly the percentage of VR females at KSU (45%) was significantly greater ($P < 0.01$) than that at MSU (25%) (Fig. 3). The average weight of BR females at KSU (33 g) was significantly greater ($P < 0.05$) that of BR females at MSU (26 g) (Fig. 6). If sexually mature female morphotypes are combined (BR + OP) there is a highly significant ($P < 0.001$) difference between sites with 76% of females at MSU and 55% of females at KSU being either egg bearing or previously egg bearing (Fig. 7). Mean individual weight of this combined class of females was significantly lower ($P < 0.05$) at MSU (27 g) than at KSU (33 g).

The relationship between the percentage of females achieving reproductive status (BR + OP) and cummulative degree days is presented in Fig. 7. Regression of the percentage of BR females on cumulative DD20s was highly significant ($P < 0.001$) for each of the locations. The general linear test (Neter and Wasserman, 1974) indicated that these regressions were not identical. Slopes of the regression lines were compared using Student's *t*-test (Snedecor and Cochran, 1980) and were found to be significantly different ($P \leq 0.05$). The proportion of females achieving egg bearing status was significantly higher relative to cumulative DD20s at MSU than at KSU. For example regression equations indicated that for 25% of females to achieve BR status 775 DD20s would required at MSU compared with 806 DD20s at KSU.

At harvest there was no significant difference in overall survival between study sites, averaging 88% and 78% at KSU and MSU, respectively (Table 2). Mean production was significantly higher ($P \leq 0.01$) at KSU (1261 kg^{-1}) than at MSU (1091 kg ha^{-1}). The average prawn weight at KSU (36.1 g) was not significantly different from that at MSU

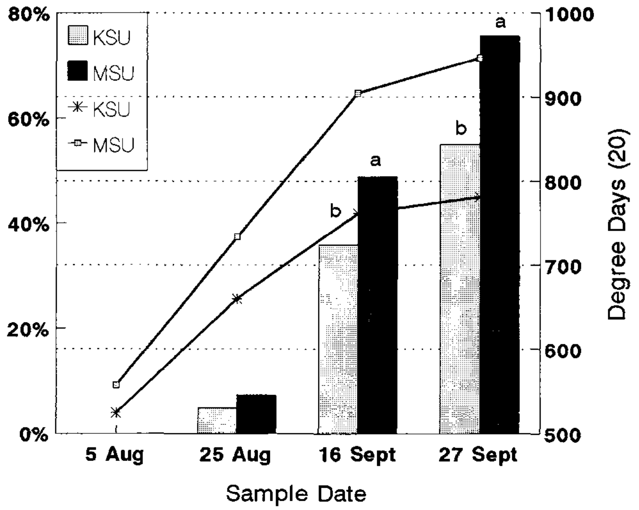

Fig. 7. Relationship between percentages of females achieving reproductive status (BR+OP) (Y_1) and cumulative DD20s (degree days > 20°C) (Y_2) at the two study locations.

(34.2 g). If the one MSU replicate with comparatively low survival is not included in the analysis then the MSU mean weight drops to 32.7 g and the difference between sites becomes highly significant ($P \leq 0.01$).

4. Discussion

Freshwater prawns are considered tropical animals requiring relatively high temperatures (29–31°C) for maximum growth (New, 1990). However, Lumare et al. (1993) found that the mean growth rate of the tropical black tiger shrimp *Penaeus monodon* cultured in a cold temperate climate (21–27°C) was similar to that reported for the same species in tropical and subtropical areas (Liu and Mancebo, 1983; Chen et al., 1989).

Table 2
Mean* (±SD) harvest weight, survival, total yield, daily yield, and feed conversion ratio (FCR) of prawns cultured at sites with different ambient temperatures (KSU, North: MSU, South)

Variable	Study site KSU	MSU
Harvest weight (g)	36.1 ± 0.4 [a]	34.8 ± 3.2 [a]
Survival (%)	88.4 ± 1.3 [a]	77.9 ± 10.3 [a]
Total yield (kg ha^{-1})	1261 ± 19 [a]	1091 ± 76 [b]
Daily yield (kg ha^{-1} day^{-1})	10.8 ± 0.2 [a]	9.4 ± 0.7 [b]
FCR	2.31 ± 0.04 [a]	2.34 ± 0.14 [b]

* Values are means ±SE of three replications at KSU and four replications at MSU. Means within a row followed by a different letter are significantly different ($P < 0.05$).

Wang (1983) reported that the redtail shrimp, *P. penicillatus*, is a warm-water species with optimum growing temperatures of 25–30°C. However, Chen et al. (1988) reported that the redtail shrimp grew faster in coldwater than warmwater. Farmanfarmaian and Moore (1978) found that in *Macrobrachium rosenbergii* feed conversion was more efficient at 25°C than 30°C (2.8 and 3.2, respectively). Tidwell et al. (1994) compared data on *M. rosenbergii* raised in ponds at a mean water temperature of 25°C with published results of similar studies at higher temperatures (27–30°C) and found higher daily yields (11.5 kg ha^{-1} day^{-1} vs. 6.6 kg ha^{-1} day^{-1}).

Lumare et al. (1993) identified three main periods during growout of *P. monodon*. During the initial period, growth rates increased rapidly to a maximum despite low temperatures (23°C). During the second phase growth rates were high and did not increase as temperature increased. Only at larger sizes (Phase III) was growth rate decreased by decreasing temperature.

In the present study, two major periods are identifiable. During Phase I, prior to animals achieving sexual maturation, temperature differences between study sites were not pronounced. At the 5 August sampling, accumulative DD20s at KSU and MSU were 525 and 557, respectively with prawn weights averaging 18 g and 15 g, respectively. Therefore, prior to the onset of sexual maturity temperature differences between sites had no negative effect on prawn growth. In fact, at the lower mean temperature (KSU) prawn growth was slightly higher. It may be that juvenile prawns under production conditions have a lower temperature optima than has been determined in lab studies utilizing larvae and post-larvae (Wiesepape, 1975). Though the optimal temperatures for prawn growth are reported to be 29–31°C (New, 1990), Johnson (1967) found that natural populations of *M. rosenbergii* in Malaysia occur at a temperature range of 24.5–25.5°C (similar to KSU conditions). In fact *M. rosenbergii* had the next to lowest temperature mean (25.1°C) of the 15 species of freshwater prawns studied.

Warren and Davis (1967) introduced the term 'scope for growth' to describe the energy a fish has available for growth and defined the term as the 'difference between the energy of the food an animal consumes and all other energy losses'. Brett (1976) found that the rapid decline in maximum growth rate (G_{max}) of sockeye salmon above 8°C was largely due to the exponential increase in maintenance ration (R_{maint}). In this study feed rates were equilibrated between study sites. Higher growth rates at lower temperatures could possibly be due to decreased maintenance requirements at the lower temperaures and a resulting increase in scope for growth at the more northerly site (KSU).

As prawns attained sexual maturity (Phase II) temperature differences appear to have had a large impact on population structures with potentially positive implications for production. A greater proportion of prawns of both sexes became sexually mature earlier at MSU than at KSU, a condition especially pronounced in females. The relationship of cumulative DD20s and proportion of females attaining reproductive status at the two sites are presented in Fig. 7.

Regression analyses indicate that these results may not be entirely controlled by cumulative temperature units, since the increase in reproductive females relative to accumulation of DD20s was significantly more rapid at MSU. This is important because attainment of sexual maturity in females normally results in decreased growth, as energy

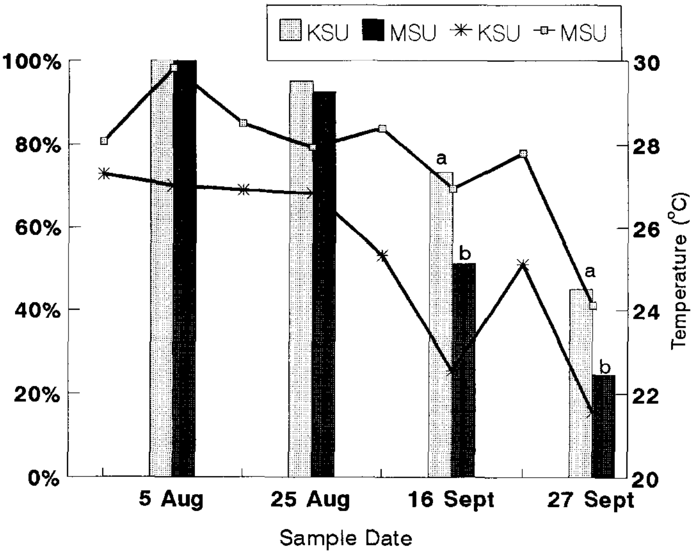

Fig. 8. Relationship between virgins (VR) as a percentage of total females (Y_1) and weekly pond temperatures (Y_2) at the two study locations.

is redirected to egg production (Karplus et al., 1986). This additional energy demand, for gonadal development, would further decrease the available scope for growth in prawns raised at the higher temperatures. Fig. 8 shows the relationship between numbers of virgin females and weekly afternoon pond temperature averages at the two study sites. This could partially explain the significantly larger sizes of mature females at KSU compared with MSU. By maturing later in the season, females at KSU would actually have a longer period of somatic growth. Females at KSU were 34% larger at the first sampling date at which mature females were found (8/25) and 22% larger at KSU than MSU at final harvest (Fig. 6).

These data are supported by the results of a study by Justo et al. (1991). They found that *M. rosenbergii* raised under controlled temperatures and photoperiods typical of higher temperate latitudes (28°C and 15 h light, 9 h dark) had a reduced frequency of reproductive molts, increased frequency of common (growth) molts, and greater growth after reproductive molts than prawns raised under conditions typical of tropical zones (32°C and 12 h light, 12 h dark). The authors stated that increased reproductive activity under tropical conditions caused a considerable draw on energy reserves and resulted in an antagonism between reproduction and somatic growth (Justo et al., 1991). Differences in day length could be the additional factor increasing the rate of female maturation at MSU relative to degree days, compared with KSU.

Delayed maturity of females could potentially delay maturation of males as the presence of mature females is a stimulus for male maturation (Cohen et al., 1981). With female maturation delayed, a greater scope for growth in males could be realized. Sexually mature BC males at KSU weighed 31%, 20%, and 9% more than at MSU at the 8/25 and 9/16 samplings and the final harvest, respectively.

5. Conclusions

The temperature difference between the MSU and KSU study sites did not negatively affect growth of immature prawns (Phase I) similar to the data reported for *P. monodon* by Lumare et al. (1993). However, differences were sufficient to delay sexual maturation at the more northerly site (KSU), especially during the period of morphotype differentiation (Phase II). (Fig. 8 illustrates the relationship between water temperature in the ponds and the numbers of VR at the two sites). Although the culture period at the two locations was exactly the same (117 days), the actual amount of energy that could be channeled to growth (scope for growth) for many individuals within the KSU population was functionally greater because of reduced maintenance requirements and the delay of sexual maturation (and its resultant slowing of growth). Differences in production and average weights at the two sites would indicate that higher overall production and average weights may be realized when water temperatures are in a range high enough to support rapid growth but low enough to suppress sexual maturation.

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