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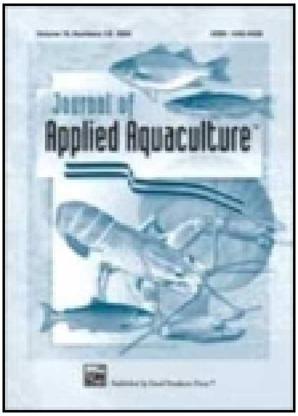

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# Effects of Stocking Density on Nursery Production and Economics of the Freshwater Prawn, Macrobrachium rosenbergii

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# Effects of Stocking Density on Nursery Production and Economics of the Freshwater Prawn, *Macrobrachium rosenbergii*

Shawn Coyle
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**ABSTRACT.** In temperate regions, post-larvae freshwater prawn, *Macrobrachium rosenbergii*, are grown to more advanced sizes in tanks prior to pond stocking. This intermediate stage of culture is referred to as the nursery period. Little research has been conducted on different management practices on juvenile prawn growth and survival during this 30-60 day period. Survival during the nursery stage has been highly variable and may be related to the cannibalistic behavior of juvenile freshwater prawn when cultured at high densities in the nursery. The objective of this study was to evaluate the effect of stocking density, relative to the provision of artificial substrate (number of prawns/m$^2$ of substrate), on growth, survival, and economic variables for freshwater prawn juveniles during nursery production. Post-larvae (0.01±0.00 g, n = 300) were stocked into nine 1900 L tanks, each provided with 20.5 m$^2$ of artificial substrate in the form of horizontal layers of black plastic mesh (10 mm) spaced 5 cm apart. Tanks were randomly assigned one of three prawn densities (215, 430, or 860 post-larvae/m$^2$ of substrate), which equated

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to 2.3, 4.6 and 9.2 prawn/L, respectively. Juvenile prawn were fed a commercial trout diet (42% protein) at a percentage of body weight according to a feed rate table. Water quality was maintained using a flow rate of 8 L/min in each tank from a reservoir pond. Temperature was maintained at approximately 28°C using heat pumps. After 56 days there was no significant difference ($P > 0.05$) in average weight of juvenile prawn stocked at the three densities ($0 = 0.58 \pm 0.12$ g, n = 9). Survival was significantly lower ($P < 0.05$) for prawn stocked at 860 $m^2$ (62%) than in those stocked at 430/$m^2$ (78%) and 215/$m^2$ (94%), which were not statistically different ($P > 0.05$). Even with reduced survival, the highest stocking density produced the greatest number of nursed juveniles based on both tank volume (5.5/l) and surface area (530/$m^2$), at the lowest average cost. *[Article copies available for a fee from The Haworth Document Delivery Service: 1-800-HAWORTH. E-mail address: <docdelivery@haworthpress.com> Website: <http://www.HaworthPress.com> © 2003 by The Haworth Press, Inc. All rights reserved.]*

**KEYWORDS.** Freshwater prawn, *Macrobrachium rosenbergii*, stocking density, economics, nursery

## *INTRODUCTION*

Freshwater prawn, *Macrobrachium rosenbergii*, culture has become increasingly popular in recent years in temperate regions of the United States, such as Kentucky, Tennessee, Georgia, and Arkansas (Tidwell and D'Abramo 2000). Achieving average harvest weights of > 30 g in the 100-140 day growing period requires that post-larvae (PL) be cultured in temperature-controlled nursery tanks to more advanced sizes prior to pond stocking.

In nursery production, prawn PL (average weight < 0.01 g) grow to an average weight ≥ 0.3 g in 30-60 days (D'Abramo et al. 1995). Nursed juveniles are more resistant than PL to predation, cannibalism, and fluctuating environmental conditions in growout ponds and produce larger average harvest sizes (Alston and Sampaio 2000). Although the nursery period is vital to prawn culture in temperate climates, relatively little research has been conducted on the effects of different management practices or environmental factors on juvenile prawn growth and survival during the nursery phase.

Survival during the nursery phase has been highly variable and may be related to the territorial and cannibalistic nature of prawn PL when

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cultured at high densities. Several authors have suggested the utilization of artificial substrates to increase two-dimensional space available to prawn as a method to increase survival and production (Smith and Sandifer 1975; Smith and Sandifer 1979). With the addition of artificial substrate, PL will utilize the full three dimensional volume of the tank, rather than just the walls and bottom (Sandifer and Smith 1975; Sandifer et al. 1983; Alston and Sampaio 2000). Alston and Sampaio (2000) reported that a wide range of stocking densities have been used in experimental nursery systems, ranging from < 200-> 6000 PL/$m^2$ of bottom area. However, optimum stocking densities have not been determined for the longer nursery periods required under temperate conditions (40-60 days) (Tidwell and D'Abramo 2000). Nurseries in temperate climates usually rely on recirculating or water exchange systems with pumps and heaters, which have relatively high energy costs. Since seed cost is a dominant variable cost in prawn production (Unpublished data), cost efficiency of nurseries has a large impact on the prices of stocker size juveniles, which significantly affects the profitability of prawn growout.

The objective of this study was to evaluate the effect of stocking density, relative to the provision of artificial substrate (number of prawns/$m^2$ of substrate), on growth, survival, and economic variables for freshwater prawn juveniles during nursery production.

## MATERIALS AND METHODS

Post-larval prawn (0.01g), purchased from a commercial hatchery (Aquaculture of Texas[1]), were stocked into nine 1,900 L conical bottom polyethylene tanks housed in a temperature-controlled greenhouse at the Aquaculture Research Center, Kentucky State University, Frankfort, Kentucky. Artificial substrate, in the form of horizontally-layered sheets (10 layers) of 0.625-cm black plastic mesh (10 mm opening) supported by a PVC frame with a 5 cm separation between layers, was added to each tank to provide 20.5 $m^2$ of total surface area. Tanks were randomly assigned one of three experimental treatments (i.e., stocking densities). The three densities were 215, 430, or 860 post-larvae/$m^2$ of substrate, which equated to 2.3, 4.6 and 9.2 prawn/L, respectively. There were three replicate tanks of each of these stocking densities.

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[1] Use of trade or manufacturer's name does not imply endorsement.

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Prawns were fed a #2 crumble (42% protein and 8% lipid) commercial trout diet (Silver Cup, Murray, Utah) according to rates and schedules recommended by D'Abramo et al. (1995). The daily ration was divided into two equal feedings (0900 and 1500).

All experimental units received approximately 8 L/minute of tempered water from an outside reservoir pond. Water temperatures in all tanks were maintained at approximately 28°C by flowing water through heat pump units. Water was circulated between the tanks and the reservoir using three ½ hp electric pumps. All tanks were aerated with air stones supplied from a regenerative blower. Water temperature and dissolved oxygen were measured twice daily (0800 and 1500) using a YSI Model 55 oxygen meter (YSI Industries, Yellow Springs, Ohio). Total ammonia-nitrogen and nitrite-nitrogen were measured in each tank 3 times per week using a DREL 2000 spectrophotometer (Hach Company, Loveland, Colorado) and pH was measured daily with a electronic pH meter (pH pen; Fisher Scientific, Cincinnati, Ohio). Un-ionized ammonia concentrations were calculated (Boyd and Zimmerman 2000).

Total duration of the experiment was 56 days; which corresponds to the normal maximum length of the nursery phase for juvenile prawn in temperate regions. Treatments were evaluated in terms of prawn growth and survival. Prawns were sampled three times during the experiment (14th, 28th and 42nd day) followed by a full harvest on the 56th day. Average weights were determined during sampling by counting 2 samples of $\geq$ 100 prawn from each tank which were group weighed and returned to the tank. Feed conversion ratio (FCR) was calculated as FCR = total diet fed (g)/total wet weight gain (g). Specific growth rate (SGR, %/day) was calculated as $SGR = [(\ln W_f - \ln W_i)]/t \times 100$, where $W_f$ = final weight, $W_i$ = initial weight, and t = time in days (Ricker 1975). Growth, survival, and water quality data were compared by analysis of variance (ANOVA) using Statistix version 4.1 (Analytical Software, Tallahassee, Florida). If ANOVA indicated significant differences among treatments, Fisher's Least Significant Difference test (LSD) was used to determine differences among means ($P < 0.05$). All percentage and ratio data were transformed to arc sin values prior to analysis (Zar 1999). Data are presented as untransformed values to facilitate interpretation.

Information of PL growth and corresponding data on stocking density and time were used to estimate a PL growth function. Established growth functional forms such as the exponential, logistic, and Von Bertalanffy growth functions were used in this estimation (Tian et al.

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1993). Goodness-of-fit measures were used to choose a single "best" growth function. The chosen growth function was then used to predict the number of days necessary for PL to achieve target weights via Monte Carlo simulations (10,000 simulations per scenario). The growth function also predicted the expected size of PL for a given number of growing days.

Daily costs of operating the nine-tank nursery were determined based on feed, utility use and hired labor data from the nursery experiment. Electricity consumption was estimated from the number of kilowatt hours needed per day to run a blower, heat pump and two water pumps, which are integral to the experimental nursery. PL price to stock the nursery was kept at \$0.025/head (C. Upstrom, Aquaculture of Texas, pers. comm.), diet price (delivered, retail price from Silver Cup, Murray, Utah) was \$1.03/kg, and electricity price was \$0.07/KWH (average retail commercial price for year 2000) (S. Dasgupta, Kentucky State University, pers. comm.). Diet quantity data (per week, per stocking density) were available from the experimental records. Hired labor requirement was assumed to be limited to 4 hours/day, which included feeding and water-quality monitoring. The blower was rated at 860 watts (operating 24 hours/day), water pumps were rated at 1,150 watts (operating 24 hours/day), and the heat pump was rated at 2,400 watts (operating approximately 80% of 24 hours/day, i.e., 19.2 hours/day). The remaining cost items were considered to be time-independent (e. g., management, maintenance, gasoline fuel, etc., and non-cash costs such as equipment depreciation), these costs did not change with the length of nursery culture and were not included in the model comparisons.

An economic efficiency indicator was used to determine the economically optimal stocking density of PL. We used Farrell's (1957) pioneering definition of production efficiency: the ability to produce a given amount of output at the lowest cost (i.e., average cost per juvenile). The "costs" included in our efficiency computations involved those items (stocking, feeding, labor, and utility expenses) that changed with stocking density and the number of PL-growing days. Other items such as management, maintenance costs, and non-cash costs (e.g., depreciation) were independent of stocking density and time, and were omitted from the average variable cost calculations. This is acceptable because only relative costs are important in comparing economic efficiency among the three stocking densities. Holding prices at the average value for year 2000, the two major sources of variation in our cost computation were mortality rate and the number of days necessary for PL to achieve a target weight. Experimental data on mortality rate (per stock-

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ing density) provided a minimum, maximum and average value. These parameters were used to define a triangular distribution on mortality rate. Triangular distributions are considered optimal for representing empirical probability distributions when only a small number of data points are available (Taha 1988). Probability distributions for the number of days required to achieve a target weight were derived from the Monte Carlo simulations described above. Using these distributions, further Monte Carlo simulations were conducted on the cost of producing juveniles of a specified target weight, under each stocking density. These simulations provided an average cost per juvenile and a 90% confidence interval, which were used to identify the least costly stocking density for a given juvenile target weight.

## *RESULTS AND DISCUSSION*

There were no significant differences in water quality values among the three treatments either by week or over the entire study period. Overall means±s.e. for water quality variables were: temperature, 28.1±0.0°C; dissolved oxygen, 6.4±0.2 mg/L; pH, 7.9±0.1; total ammonia-nitrogen, 0.52 ± 0.01 mg/L; un-ionized-ammonia, 0.03±0.01; and nitrite-nitrogen, 0.08±0.01 mg/L. These values represent suitable culture conditions for prawn juveniles (New 1995).

After 56 days, there was no significant difference ($P > 0.05$) in average weight of juvenile prawn stocked at the three densities (Table 1). Survival was significantly lower ($P < 0.05$) in prawn stocked at the high stocking density 860/m$^2$ (62%) compared to other treatments (Table 1). Differences in survival of prawn stocked at 215/m$^2$ (94%) and 430/m$^2$ (78%) were not statistically significant ($P > 0.05$) (Table 1). Total production in terms of numbers of juveniles produced per m$^2$ of substrate was positively related to increased stocking density. Prawn stocked at 860/m$^2$ resulted in significantly greater numbers of juveniles produced (5.5/L and 527/m$^2$) compared to the other treatments. PL stocked at 430/m$^2$ also resulted in significantly greater ($P < 0.05$) numbers of juveniles produced (3.6/L and 347/m$^2$) compared to PL stocked at 215/m$^2$ (2.2/L and 208/m$^2$). FCR for PL stocked at 860/m$^2$ (3.2) was significantly greater ($P < 0.05$) than for those stocked at 215/m$^2$ (1.4) (Table 1). FCR values for PL stocked at 430/m$^2$ were not significantly different from other treatments (Table 1). Differences in FCR are primarily re-

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TABLE 1. Mean±SE for production characteristics of juvenile freshwater prawn stocked at either 215, 430, or 860 post-larvae/m$^2$ of substrate in tanks for 56 days; values are means of three replicate tanks for each density. Means within each row followed by different letters are significantly different ($P \leq 0.05$).

| | Stocking Density (#/m$^2$ of substrate) | | |
|---|---|---|---|
| | 215 | 430 | 860 |
| Mean weight on 14th day (g) | 0.053±0.009 | 0.052±0.008 | 0.045±0.002 |
| Mean weight on 28th day (g) | 0.178±0.061 | 0.140±0.045 | 0.128±0.038 |
| Mean weight on 42th day (g) | 0.496±0.132 | 0.423±0.106 | 0.292±0.045 |
| Mean weight on 56th day (g) | 0.693±0.140 | 0.587±0.148 | 0.470±0.072 |
| Survival (%) | 93.6±6.2a | 78.1±10.6a | 61.8±6.3b |
| Total production (number/L) | 2.17±0.14c | 3.62±0.49b | 5.49±0.59a |
| Total production (number/m$^2$) | 207.9±13.8c | 347.1±47.3b | 527.2±56.5a |
| Feed Conversion Ratio | 1.40±0.34b | 1.98±0.31ab | 3.20±0.79a |

lated to differences in survival as prawns were fed based on a feeding table and survival was assumed to be 100%.

While final average weight differences were not statistically significant, there was a negative relationship between stocking density and average prawn weight. This would suggest that optimum PL stocking densities in nursery tanks will depend upon the target size of the nursed juvenile as well as the duration of the nursery period and that the duration of the nursery period may be shortened when PL are stocked at lower densities.

The data from the present study are in agreement with Sandifer et al. (1983) who suggested that stocking density should be inversely proportional to the culture period, where higher stocking densities result in lower survival percentages. Under similar conditions (indoor tanks), Smith et al. (1983) reported 89% survival for prawn PL stocked at 211 PL/m$^2$ and nursed for 73 days, 71% survival for prawn stocked at 363/m$^2$ for 77 days, and 61% survival when stocked at 681/m$^2$ and nursed for 89 days. In situations where post-larvae prawn are expensive or difficult to obtain and high survival is essential to the nursery operator, relatively low stocking densities (200-400/m$^2$) and/or culture periods (40-50 d) may be advantageous.

Using average prawn weights from this study, a growth function which estimated PL weight with respect to stocking density and time

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was developed. Of the different potential functional forms for growth, the exponential, logistic and Von Bertalanffy growth functions showed the most promise (Tian et al. 1993).

$$\text{Exponential: } W(t) = \text{Exp}\,[\underset{-22.950}{-3.440} - \underset{-2.894}{0.263}\,(\text{Stock-Density}/\bar{S}) + \underset{19.156}{2.083}\,(t/\bar{t})]$$

$$\text{Logistic: } W(t) = 1/[1 + \text{Exp}(\underset{16.875}{3.583} + \underset{3.568}{0.460}\,(\text{Stock-Density}/\bar{S}) - \underset{-18.484}{2.847}\,(t/\bar{t})]$$

$$\text{Von Bertalanffy: } W(t) = 1 - \text{Exp}[\{\underset{-5.164}{-0.273} + \underset{4.471}{0.124}(\text{Stock-Density}/\bar{S}) - \underset{-12.568}{0.517}\,(t/\bar{t})\}^3]$$

The above equations report the estimated growth functions, with t-ratios appearing below corresponding parameter estimates (all estimated parameters were significantly different from zero, for $\alpha = 5\%$). In these equations, W and t stands for weight (g) and time (days), respectively; $\bar{S}$ and $\bar{t}$ refer to the average value of stocking density (per $m^2$) and the number of days, respectively, reported in the sample data. The exponential growth function ($R^2 = 91.92\%$, Adjusted $R^2 = 91.43\%$), was selected over the logistic ($R^2 = 91.48\%$, Adjusted $R^2 = 90.97\%$) and Von Bertalanffy ($R^2 = 89.14\%$) growth functions. A Jarque-Bera normality test indicated that the residuals were not distributed significantly different from a normal distribution (test statistic = 1.7463, p-value = 0.418). A heteroskedasticity test (Glejser's test statistic = 2.253, p-value = 0.324) indicated acceptance of the homoskedasticity null assumption.

The estimated variance-covariance matrix from the exponential growth function regression provided the necessary variability parameters of the coefficients in order to develop Monte-Carlo simulations. These simulations identify, for each stocking density, the expected number of days required for PL to achieve a target size and the expected size of PL after a given number of growth-days.

Table 2 reports the expected weight of PL from 15 growth days to 55 growth days, in 5-day increments, for each of the three stocking densities. Clearly, PL grow faster at lower stocking densities. Table 3 reports the expected number of days required for PL to achieve a target size, for each of the three stocking densities. PL take less time, on average, to reach a target size, when stocked at lower densities. Interestingly, Table 3

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TABLE 2. Mean predicted weight of juveniles, in grams, (and the 90% confidence interval) at three PL stocking densities, with respect to the number of days of growth.

| | Stocking Density ($\#/m^2$ of substrate) | | |
|---|---|---|---|
| Days | 215 | 430 | 860 |
| 15 | 0.07 (0.06 to 0.10) | 0.06 (0.05 to 0.09) | 0.05 (0.04 to 0.08) |
| 20 | 0.10 (0.08 to 0.13) | 0.09 (0.07 to 0.12) | 0.07 (0.05 to 0.12) |
| 25 | 0.13 (0.10 to 0.19) | 0.12 (0.09 to 0.17) | 0.09 (0.07 to 0.17) |
| 30 | 0.17 (0.13 to 0.26) | 0.16 (0.12 to 0.24) | 0.13 (0.09 to 0.23) |
| 35 | 0.23 (0.18 to 0.36) | 0.21 (0.16 to 0.33) | 0.17 (0.12 to 0.32) |
| 40 | 0.32 (0.24 to 0.50) | 0.28 (0.21 to 0.46) | 0.23 (0.16 to 0.43) |
| 45 | 0.43 (0.32 to 0.71) | 0.38 (0.28 to 0.65) | 0.31 (0.21 to 0.60) |
| 50 | 0.58 (0.42 to 0.98) | 0.52 (0.37 to 0.91) | 0.42 (0.29 to 0.71) |
| 55 | 0.78 (0.56 to 1.35) | 0.70 (0.50 to 1.29) | 0.56 (0.38 to 0.97) |

TABLE 3. Mean number of predicted days (and the 90% confidence interval) for juveniles to reach a target size, at three PL stocking densities.

| | Stocking Density ($\#/m^2$ of substrate) | | |
|---|---|---|---|
| Size | 215 | 430 | 860 |
| 0.25 g | 37 (32 to 42) | 38 (33 to 45) | 42 (35 to 50) |
| 0.30 g | 40 (35 to 46) | 42 (36 to 48) | 45 (39 to 53) |
| 0.35 g | 42 (37 to 49) | 44 (39 to 51) | 48 (41 to 56) |
| 0.40 g | 44 (39 to 51) | 46 (41 to 53) | 50 (43 to 58) |
| 0.45 g | 46 (41 to 53) | 48 (43 to 56) | 52 (45 to 60) |
| 0.50 g | 48 (43 to 55) | 50 (45 to 58) | 54 (47 to 62) |

shows that while there is a 2-day gap between the expected number of days to reach a target size between $215/m^2$ and $430/m^2$ stocking densities, the time gap increases to 4 days between $430/m^2$ and $860/m^2$ stocking densities. This suggests that both absolute and relative magnitude of stocking density affect the differential growth rates of PL.

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Data indicate that growth rate of PL are dependent on stocking density and time; mortality rate is also dependent on stocking density, among other factors such as water quality. Hence, stocking density is a major determinant of the total production volume from the nine-tank nursery. If one were to determine an optimal stocking density, biological efficiency and economic efficiency indicators are needed to develop judgment criteria. If mortality and growth rate are used as biological efficiency indicators, the 215/m$^2$ stocking density should be the most biologically efficient (i.e., lowest mortality and highest growth rate). However, economic efficiency considerations, a major determinant of real-world nursery operations, might indicate a different stocking density.

Table 4 reports the average variable cost per juvenile for different target weights in each stocking density. Clearly, the least expensive method of producing juveniles, for any target weight from 0.25 to 0.50 g, involves stocking at 860 PL/m$^2$ instead of stocking at 430 PL/m$^2$ or at 215 PL/m$^2$. This result is not surprising because, despite lower survival rates and growth rates, the total production volume of juveniles at the higher stocking densities was significantly higher than at the lower stocking densities. Hence, the experimental data indicate that 860 PL/m$^2$ is the most economical of the three stocking densities tested.

## *CONCLUSIONS*

Even with reduced survival, the higher stocking density (860/m$^2$) produced greater numbers of nursed juveniles on a per-liter (5.5/L) and

TABLE 4. Mean variable cost per juvenile ($/head), and the 90% confidence interval, for a given target size, at three PL stocking densities.

| | Stocking Density (#/m$^2$ of substrate) | | |
|---|---|---|---|
| Size | 215 | 430 | 860 |
| 0.25 g | $0.13 ($0.11 to $0.15) | $0.09 ($0.08 to $0.11) | $0.07 ($0.065 to $0.10) |
| 0.30 g | $0.14 ($0.12 to $0.17) | $0.09 ($0.08 to $0.12) | $0.08 ($0.07 to $0.10) |
| 0.35 g | $0.15 ($0.13 to $0.17) | $0.10 ($0.09 to $0.13) | $0.08 ($0.07 to $0.11) |
| 0.40 g | $0.15 ($0.14 to $0.19) | $0.10 ($0.09 to $0.14) | $0.09 ($0.08 to $0.11) |
| 0.45 g | $0.16 ($0.14 to $0.20) | $0.10 ($0.09 to $0.14) | $0.09 ($0.08 to $0.12) |
| 0.50 g | $0.17 ($0.15 to $0.20) | $0.11 ($0.09 to $0.15) | $0.09 ($0.08 to $0.12) |

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per-m$^2$ (527/m$^2$) basis than lower densities with no significant decrease in average weights. Average variable cost computations indicate that the 860/m$^2$ stocking density was the most economical choice of the three stocking densities. However, the average costs calculated for this study would be much higher if it included management, maintenance or non-cash expenditures. When compared with contemporary retail prices of 60-day nursed juveniles in the United States ($0.10-$0.12/head from most prawn nurseries), it is clear that our experimental nursery is not economically competitive. While high stocking densities are associated with lower survival rates and slower growth rates, this paper demonstrates that high stocking rates produce the highest number of juveniles at the lowest average costs within a 60-day time period that is conducive for nurseries in temperate climates.

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