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Shrimp Yields and Economic Potential of Intensive Round Pond Systems

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Abstract

Three intensive growout trials using *Penaeus vannamei* were conducted in round ponds in Hawaii in 1987. A 337 m^2 experimental pond was stocked at 100 shrimp/m^2 for two trials; a 2,000 m^2 commercial prototype pond was stocked at 75/m^2 for one trial.

In the experimental pond trials, shrimp survival averaged 88 ± 10% (SE) and feed conversion averaged 2.2 ± 0.2. Growth averaged 1.5 ± 0.3 g/week, yielding 18.2 ± 1.7 gram shrimp in 80 ± 5.5 days. Combined production in the experimental trials was 32,272 kg/ha in 174 days (from stocking of trial 1 to harvest of trial 2). Comparing these results to 1986 results (Wyban and Sweeney 1988), it was concluded that shrimp growth is not affected and production is doubled by increasing stocking density from 45/m^2 to 100/m^2.

Pooling data from 1986 and 1987, a significant linear regression was obtained when weekly growth of shrimp above four grams individual size was regressed on mean weekly pond temperature: growth = 0.37 * temperature − 8.44; (r^2 = 0.41; $P < 0.01$). Multiple regression to examine effects of shrimp size, pond biomass, and shrimp age on the temperature-growth relationship was not significant.

In the commercial prototype pond trial, survival was 67% and feed conversion was 2.0. Growth averaged 1.4 g/week, yielding 18.1 gram shrimp in 88 days. Production was 9,120 kg/ha. Individual shrimp size distribution at harvest in the commercial pond was similar to experimental pond results, indicating that shrimp growth in the two systems was comparable.

Financial characteristics of a hypothetical 24 pond shrimp farm using these results were determined using an electronic spreadsheet model (Leung and Rowland 1987). Feed costs were 40% of total operating costs while postlarvae and labor were 14% and 16% of total operating costs, respectively. Breakeven price (BEP) was far more sensitive to changes in revenue-determining inputs such as survival and growth than to comparable changes in cost-determining inputs such as feed and postlarvae costs.

Together these results suggest that commercial scale round pond production mimics experimental scale production and that round pond technology has commercial potential.

United States shrimp aquaculture will have to be intensive to compete in a global market. Land, labor, and material expenses create high fixed costs which can only be offset by high revenues. This research program is dedicated to developing an intensive shrimp culture system suited to Hawaii and mainland U.S. conditions. Knowing that shrimp survival, growth rate, and stocking density are the most powerful influences on economic performance (Wyban et al. 1987), this study was developed to determine what design and management system would maximize shrimp growth rate, density, and survival. After reviewing intensive shrimp systems worldwide, it was hypothesized that the optimum intensive shrimp system is a self-cleaning round earthen pond. Paddlewheels would aerate and mix the water so that high shrimp stocking densities and high feeding rates could be managed.

In fall 1985 a 337 m^2 experimental round pond was designed and constructed at Oceanic Institute. The 1 m deep pond had an earthen bottom, vertical concrete walls, a 20 cm diameter center drain and a single 1 hp paddlewheel for mixing the water.

In 1986, three growout trials were conducted in the experimental pond using the white shrimp, *Penaeus vannamei.* Shrimp were stocked at a density of 45 shrimp/m^2, and excellent growth and production were achieved in replicated trials (Wyban and Sweeney 1988). In 1987, studies were undertaken to determine: 1) if the same growth and survival rates could be obtained at higher densities, and 2) if production similar to that obtained in the experimental pond could be achieved in a 0.2 ha commercial prototype round pond.

Results of the first experiments indicate that increasing stocking density from 45 shrimp/m^2 to 100 shrimp/m^2 in the experimental pond had little effect on shrimp growth and survival, while production doubled. Results of the commercial prototype pond trial indicate that production levels achieved in the experimental pond can be duplicated at commercial scale.

Ongoing financial analyses of these systems suggest excellent performance. Financial characteristics of a hypothetical 24 pond farm were determined and indicate that this technology has commercial potential.

Methods

A detailed description of round pond management procedures is given in Wyban and Sweeney (1988). Specific pathogen free *Penaeus vannamei* from the Amorient Aquaculture, Inc. (Kahuku, Hawaii, USA) hatchery were used in all trials. In the experimental pond trials (1 and 2), postlarvae were nursed in 6 m round fiberglass tanks and received commercial feed (Hanaqua Feed Corp., Taipei, Taiwan, R.O.C.) for 40 days prior to pond stocking. In the prototype pond (trial 3), shrimp were nursed for 40 days in a 1 acre earthen pond and were fed freshwater prawn pellets (Waldron's Feed Co., Honolulu, Hawaii, USA).

In trials 1 and 2, juvenile shrimp (1.2 ± 0.14 g) were stocked at 100/m^2 of pond bottom area. In trial 3, shrimp (0.9 ± 0.11 g) were stocked at 75/m^2. Trial 1 was stocked 28 March 1987 and harvested 23 June 1987. Trial 2 was stocked 6 June 1987 and harvested 18 September 1987. Trial 3 was stocked 28 August 1987 and harvested 24 November 1987. Shrimp growth was estimated weekly in all trials by weighing at least 100 individual shrimp captured by cast net. Shrimp were returned to the ponds following sampling.

TABLE 1. *Assumptions used in financial analysis of hypothetical marine shrimp farm in Hawaii.*

Round Pond Farm	
Design:	
Shrimp species	*P. vannamei*
Total pond area (ha)	4.8
Growout pond size (ha)	0.2
Number of ponds	24
Pond shape	Round
Construction costs/pond ($):	
Excavation	15,250
Cement work	6,500
Plumbing	6,000
Electrical	2,500
Farm operation—nursery system:	
Pond size (ha)	0.1
Number of ponds	3
Stock dens (#/m^2)	1,000
Stocking material	PL5
Growing season (mos/yr)	12
PL costs ($/1,000)	10
Feed costs ($/kg)	1.25
Feed conversion ratio	2.0
Water exchange (%/day)	40
Nursery period (days)	40
Survival (%)	80
Product	1 g seed
Growout system:	
Pond size (ha)	0.2
Stocking density (#/m^2)	100
Survival (%)	80
Stocking weight (g)	1
Harvest weight (g)	20
Period/crop (days)	84
Feed conversion ratio	2.3
Feed cost ($/kg)	1.25
Crops/year	3.75
Yield/crop/pond (kg)	3,200
Water exchange (%/day)	60
Paddlewheels/pond (hp/ha)	4 (20)
Electricity ($/kwh)	0.09

In all three trials, a 38% protein commercial shrimp feed from Taiwan (Hanaqua) was used (see Wyban and Sweeney 1988 for proximate analysis). Feed rates were adjusted twice weekly based on individual shrimp body weight, estimated survival, an optimal feed curve (Wyban and Sweeney 1988) and visual observation of shrimp feed consumption. On the day following shrimp feed increases, a diver would

TABLE 2. *Temperature, dissolved oxygen concentration, secchi visibility, ammonia concentration, and pH in 1987 round pond trials. (SEM = standard error of the mean.)*

		Trials 1 and 2		Trial 3	
		A.M.	P.M.	A.M.	P.M.
Temp (C)	Mean	25.2[a]	28.1[b]	25.5	27.2
	SEM	0.2	0.2		
DO (mg/L)	Mean	6.5[a]	12.1[b]	4.4	9.3
	SEM	0.2	0.4		
Secchi (cm)	Mean	43.3	44.1	N/A	N/A
	SEM	1.3	1.2		
Ammonium (mg/L)	Mean	0.24	N/A	N/A	N/A
	SEM	0.02			
pH	Mean	7.6	N/A	N/A	N/A
	SEM	0			

[a,b] Different superscripts across rows indicate significant differences ($P < 0.01$).

TABLE 3. *Water exchange rates expressed as % of total pond volume exchanged per day in Trials 1 and 2.*

	Trial 1	Trial 2	Mean
Mean	47.5	74.1	60.8
SEM	3.2	3.6	13.3
Min	1.4	22.2	1.4
Max	84	106	106

swim through the pond and determine the amount of feed left over from the previous day. If more than 500 g remained, feed rate was reduced.

In trials 1 and 2, dissolved oxygen concentration (DO), temperature, and secchi visibility were monitored twice daily at 0800 h and 1600 h. NH_4-N was determined weekly. Daily water exchange was adjusted to maintain secchi visibility above 30 cm and was recorded by a water meter in the experimental pond. In trial 3, only DO and temperature were measured twice daily at 0200 h and 1300 h.

Financial analyses were performed using the electronic spreadsheet financial model developed by Leung and Rowland (1987). A hypothetical shrimp farm consisting of twenty-four 2,000 m^2 round growout ponds was assumed. Construction costs were based on costs incurred in constructing the commercial prototype pond used in trial 3. Production assumptions were based on results achieved in 1987 trials in the experimental pond. Other assumptions used as inputs to the model are listed in Table 1.

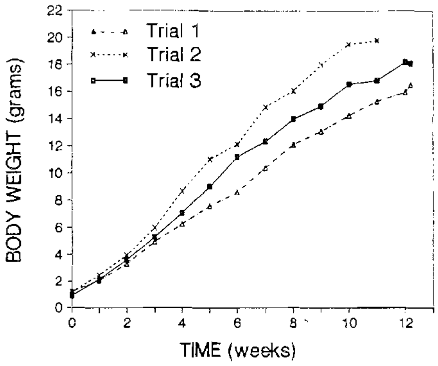

FIGURE 1. *Individual shrimp growth in experimental round pond trials 1 and 2 and in the commercial prototype trial 3.*

Sensitivity analyses were derived by calculating the mean change in breakeven price (BEP) from a series of incremental (10%) changes in single inputs to the financial model. Results are expressed as the absolute change in BEP (in dollars) per 10% change in input variable. Care was taken to vary production parameters within realistic ranges.

Results

Experimental Pond

Mean afternoon pond temperature and dissolved oxygen concentration were significantly higher ($P < 0.01$) than in the morning (Table 2). Trial 2 mean daily water temperature (27.8 C) was greater than trial 1 (25.3 C). Dissolved oxygen concentrations were always above 4.0 mg/L. Mean ammonia concentration was 0.24 ± 0.02 mg/L in trials 1 and 2. Mean daily water exchange in the two trials was 60.8 ± 13.3 percent of pond volume per day (Table 3).

Shrimp growth rate in trial 2 was consistently greater than that observed in trial 1 (Fig. 1). Weekly shrimp growth from 4 to 20 grams in trials 1 and 2 appeared to be related to weekly mean pond temperature

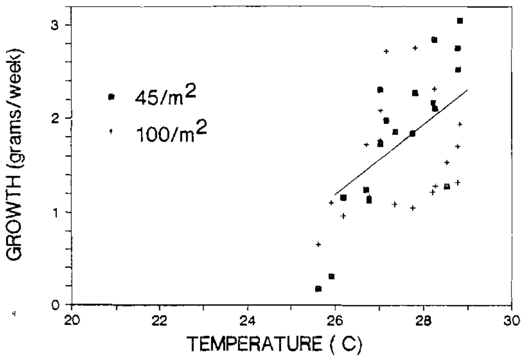

FIGURE 2. *Mean weekly shrimp growth from 4 to 20 grams versus weekly mean pond temperature in 1986 and 1987 experimental round pond trials. Equation of regression line is: Growth = 0.37 * temperature − 8.44; growth units are g/wk and temperature (C); $r^2 = 0.41$; P < 0.01.*

($r^2 = 0.22$; $P = 0.05$). Growth rates in 1986 and 1987 were not significantly different. Pooling 1986 and 1987 weekly growth data revealed a stronger relationship between growth and temperature ($r^2 = 0.41$; $P < 0.01$). Multiple regressions incorporating shrimp size, pond biomass, shrimp age, weekly growth and pond temperature yielded lower r^2 values. Pooled 1986 and 1987 weekly growth versus mean weekly pond temperature are plotted in Fig. 2.

Shrimp production data are presented in Table 4. Total shrimp production in trials 1 and 2 was 32,272 kg/ha in 174 days (from stocking of trial 1 to harvest of trial 2). Size frequency distribution of 150 randomly selected shrimp at the harvest of trial 2 is illustrated in Fig. 3.

Commercial Pond

Dissolved oxygen concentrations and temperature values in trial 3 were similar to the mean values in the experimental trials (Table 2). Similarly, shrimp growth rate (1.4 g/wk), food conversion ratio (2.0), and harvest size were not different from those achieved in the experimental trials (Table 4). Survival in the commercial pond was lower than in the experimental trials. Two problems that developed during the trial may explain the lower survival. First, there was a question of whether the stated number of animals were actually stocked in the pond. Second, electrical failure disrupted paddlewheel operation in week three, resulting in a dissolved oxygen decline to 0.6 mg/L and a partial shrimp kill. Total production in the commercial trial was 9,120 kg/ha. Size frequency distribution of shrimp at harvest in the commercial trial was very similar to that in the experimental trials (Fig. 3).

TABLE 4. *1987 round pond shrimp production data. Experimental pond data (Trials 1 and 2) are mean ± SD (N = 2). Trial 3 data are from single commercial pond trial.*

Parameter	Trials 1 and 2	Trial 3
Stocking wt (g)	1.2 ± 0.0	0.9
Density (#/m^2)	100	75
Harvest wt (g)	18.2 ± 1.7	18.1
Duration (d)	80 ± 5.5	88
Survival (%)	88 ± 10	67
Feed conversion	2.2 ± 0.2	2.0
Daily biomass increase ($g/m^2/d$)	18.5 ± 3	10.3
Growth rate (g/wk)	1.5 ± 0.3	1.4
Total production (kg/ha)	16,136 ± 3,268	9,120

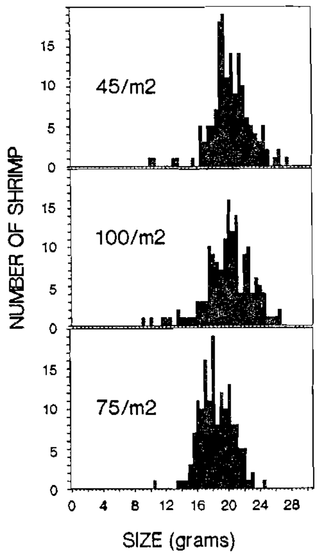

FIGURE 3. *Individual shrimp body weight distribution of 150 randomly sampled shrimp from 1986 trial (45/m^2); 1987 trial 2 (100/m^2); and the 1987 commercial trial 3 (75/m^2).*

TABLE 5. *Annual operating costs as percent of total annual operating costs for hypothetical 24 pond round pond farm.*

Average annual operating costs	
Cost area	% of total operating costs
Variable costs:	
Postlarvae	14
Feed	40
Pumping	3
Electricity	1
Fuel	3
Labor	12
Salaries	4
Excise tax	1
Subtotal	78
Fixed costs:	
Contingency	5
Interest	1
Depreciation	4
Lease	3
Other	9
Subtotal	22
Total annual cost:	100

Financial Analysis

A summary of annual operating costs for a hypothetic round pond farm (Table 5) shows that the cost for feed, postlarvae and labor are the most important and represent 70% of total operating costs. Breakeven price was most affected by changes in survival, followed by growth rate (crop period), stocking density and feed costs (Table 6).

Discussion

During experimental pond trials, water quality was excellent. Morning DO averaged 6.5 mg/L and NH_4 averaged 0.24 mg/L even though feeding rates reached 67 grams/m^2/day. High water exchange rates (mean of 60% of pond volume/day) may have only partly accounted for the excellent water quality. Feeding rates exceeded rates applied in the intensive culture of *Penaeus japonicus* (up to 40 grams/m^2/day) in Japan, where water exchange may reach 300%/day (Shigueno 1985).

A major determinant of round pond water quality during the day was the diatom-dominated algal bloom observed in both the experimental and prototype ponds (unpublished data). During the day, DO would increase from 6.3 mg/L in the morning to over 12 mg/L in the afternoon as a result of intense photosynthetic activity. At night, when phytoplankton respiration consumes oxygen, O_2 was supplied by paddlewheel. In addition to its oxygen production, the phytoplankton probably played an important role in absorbing ammonia released by shrimp metabolism. Ammonium in the pond never exceeded 0.35 mg/L throughout the trials.

TABLE 6. *Sensitivity analysis of breakeven price (BEP) to incremental changes in input assumptions for hypothetical farm. Results are expressed as absolute change in BEP ($) per 10% change in input parameter.*

	Range tested	Delta BEP ($)
Cost factors:		
Feed ($/kg)	$0.88–$1.25	0.27
PLs ($/1,000)	$6.00–$10.00	0.09
Water (%/day)	42–60%/day	0.04
Construction ($/pond)	$15,850–$21,750	0.01
Revenue factors:		
Survival (%)	76–88	0.88
Period (mo/crop)	2.1–3.0 mo	0.57
Density (#/m^2)	100–130	0.41

Diatom-dominated algal blooms are generally considered favorable in shrimp ponds (Shigueno 1985; Wyban et al. 1987). Diatoms may play an important role in shrimp nutrition as well as in managing water quality. Diatoms possess high levels of polyunsaturated fatty acids (Orcutt and Patterson 1974) which are known to promote shrimp growth (Kanazawa et al. 1979). Recent laboratory studies have shown that shrimp pond water dramatically stimulates shrimp growth compared to clean well water (Leber and Pruder 1988).

These trials demonstrate that *P. vannamei* is capable of fast growth to 20 grams with high survival when stocked at 100/m^2. Previous studies of intensive shrimp culture are reviewed in Wyban and Sweeney (1988). Comparing trials 1 and 2 to 1986 trials (Wyban and Sweeney 1988), increasing stocking density from 45 to 100 shrimp/m^2 did not appear to affect shrimp growth or survival. In pond trials in South Carolina, increased stocking densities up to 100/m^2 have had no apparent effect on *P. vannamei* growth or survival (Stokes et al. 1988).

Because management inputs (e.g., feed inputs and water exchange) were also increased in 1987 compared to 1986, an important issue is whether the increased costs were economically justified. An efficiency analysis of increased feed and water exchange indicate that these increases were justified. Feed costs per kg of shrimp produced in 1987 ($2.09/kg) actually decreased compared to 1986 ($2.38/kg) while water pumping (total water per kg of shrimp) decreased from 47,535 L/kg in 1986 to 30,244 L/kg in 1987.

The effect of pond temperature on shrimp growth has important implications. Crustacean metabolism is strongly affected by temperature (McLeese 1956; McFarland and Pickens 1965; Vernberg and Moreira 1974; Pezzack and Corey 1982). In the freshwater prawn, *Macrobrachium rosenbergii,* growth rate doubles for every 5 C increase in temperature (Farmanfarmaian and Moore 1978). The specific mechanisms involved in temperature effects on crustacean growth are not well understood. Because of the significant impact that growth rate has on economic performance (see below), temperature effects on growth in shrimp should be further studied.

We consistently observed reduced feeding when morning pond temperatures decreased below 25 C. It would be useful to know whether this effect is primarily metabolic or behavioral. If principally behavioral, alternative management practices such as modified diets may reduce the effects of pond temperature on shrimp growth and production.

Site selection for intensive shrimp systems will have a major impact on total farm production potential. Since pond temperature is strongly correlated with air temperature (Wyban and Sweeney 1988), leeward areas in Hawaii, where mean daily air temperature is highest, would be preferable to cooler windward locations. Integrating round pond technology with passive solar technology or waste thermal effluents could increase a system's total shrimp production potential.

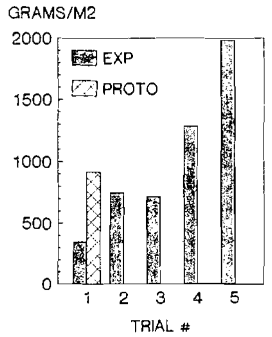

FIGURE 4. *Shrimp production in 1986 (trials 1, 2 and 3) and 1987 (trials 4 and 5) experimental round pond trials (labeled Exp) and in the commercial trial (labeled Proto).*

Shrimp growth rate in the commercial prototype was similar to that observed in the experimental round pond. The narrow individual weight distribution obtained in the commercial pond further indicates that shrimp growth was uniform and similar to experimental pond results.

Total production in the round pond systems has steadily increased in two years of operating the experimental pond (Figure 4). The increases within each year were mostly due to increased pond temperatures in the later trials which were conducted during the summer. The increase in production from year 1 to year 2 resulted from increased stocking density and improved methods. The first trial in the commercial pond yielded 9,120 kg/ha, and it is anticipated that production in that pond will also increase in subsequent trials as management is refined.

In South Carolina, application of Taiwanese methods to pond culture of *P. vannamei,* at an average density of 43 shrimp/m^2, yielded 6,700 kg/ha in 153 days (Sandifer et al. 1987). For comparative purposes, the combined production of trials 1 and 2 in the 1987 study (32,272 kg/ha) was produced in 174 days (excluding nursery periods). While pond temperatures in the South Carolina study (mean = 26.4 C) and this study (mean = 26.5 C) were nearly identical, important differences in pond design and management probably account for the differences in shrimp growth rate. Nursed juveniles were used in the round pond trials while direct PL-stocking was used in the South Carolina study. Higher water exchange rates were also used in the round pond trial. The trials reported here demonstrate that the round pond design and management yield high shrimp growth rates and production.

In the hypothetical round pond farm, feed costs represented 40% of the total operating costs. Although expensive at $0.95/kg (FOB-Taiwan), Taiwanese feed's performance is quite high. In Japanese intensive shrimp culture systems, feed constitutes 30% of total operating costs (Shigueno 1985). In Taiwanese intensive farms, feed constitutes 42–52% of operating costs, depending on farm organization (Chiang and Liao 1985).

In the hypothetical round pond farm, postlarvae costs and feed costs represented 14% and 40% of total operating costs respectively. They were 25% and 20% respectively in a previous financial analysis of semi-intensive farms in Hawaii (Wyban et al. 1987). An inverse relationship between percent total costs represented by feed costs and PL costs has been described for shrimp culture in Asia as production intensity increases (Hirasawa 1985).

Overall, breakeven price (BEP) for a round pond farm is far more sensitive to incremental changes in revenue-determining inputs than to comparable changes in cost-determining inputs. A 10% increase in survival reduces BEP $0.88/kg, while a 10% increase in growth rate reduces BEP by $0.57/kg. This conclusion concurs with sensitivity analyses in semi-intensive systems (Wyban et al. 1987).

These economic characteristics can be used to prioritize resource allocation in both research and commercial systems. The strong influence of survival and growth rate on BEP indicate that these are the critical factors on which producers and researchers should focus. Since growth rates and survival are both measures of shrimp health and well-being, growth rate may be the priority target for research. Generally, if shrimp growth is excellent, survival will be high. Greater emphasis should be placed on optimizing shrimp culture conditions so that both shrimp growth rate and survival are maximized.

Acknowledgments

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