JOURNAL OF THE
WORLD AQUACULTURE SOCIETY

Vol. 20, No. 1
March, 1989

Paddlewheel Effects on Shrimp Growth, Production and Crop Value in Commercial Earthen Ponds

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Abstract

The effects of continuous paddlewheel operation on shrimp growth, yield and crop value were studied in Hawaii. Six 0.4 ha earthen ponds were stocked with *Penaeus vannamei* at 25 postlarvae/m^2. Three ponds served as controls with no mechanical aeration or mixing. Each of the other three ponds had two 1 hp paddlewheel aerators (3.7 kw/ha) running continuously throughout the five month trial (29 April–8 October 1986). All other management factors were applied uniformly.

Daily water temperature and use were significantly different between treatments. Paddlewheel ponds had lower water temperatures (28.3 vs. 28.5 C) and lower water use (0.8% exchange per day vs. 2.2% exchange per day) than control ponds.

Faster shrimp growth in paddlewheel ponds was evident in week 8. At week 14, mean shrimp body weights and growth rates were significantly greater. Shrimp at harvest were 21.2 ± 2.6 g in paddlewheel ponds versus 15.3 ± 2.6 g in control ponds. Mean shrimp production was 2,852 ± 222 kg/ha in paddlewheel ponds compared to only 2,061 ± 558 kg/ha in controls. Mean crop value was $13,719 per pond per crop for paddlewheel ponds versus $9,111 for control ponds. Hence, paddlewheels afforded an increase of 42% in net crop value after subtracting purchase and operating costs.

Financial analyses of semi-intensive shrimp production in the U.S. have shown that improving survival, stocking density, and growth rates has a greater impact on economic performance than comparable cost reductions (Griffin and Richardson 1987; Rhodes et al. 1987; Wyban et al. 1987a). Increasing these parameters is therefore a high priority for the developing U.S. shrimp farming industry, and can be achieved through intensification, where inputs per unit area are higher.

Intensive shrimp production has been commercially successful in Taiwan where shrimp farmers achieve 3,000–5,000 kg/ha/crop (Liao and Chao 1983). In the Philippines, application of Taiwanese shrimp production techniques yielded 3,900 kg/ha in 106 day crops (Liu and Mancebo 1983). In South Carolina, experimental application of Taiwanese methods resulted in yields of 6,700 kg/ha/crop (Sandifer et al. 1987). These studies used paddlewheel aeration and mixing, a routine management practice of Taiwanese farmers (Chiang and Liao 1985), and a critical factor in high levels of production. This study examined the effects of continuous paddlewheel use on shrimp growth rate, production, and net crop value in commercial shrimp ponds in Hawaii. The results indicate that continuous use of paddlewheels in shrimp growout ponds is cost-effective.

Materials and Methods

The effects of paddlewheels were studied in six 0.4 ha earthen ponds at a commercial farm (Amorient Aquaculture International, Inc.) at Kahuku, Hawaii, USA. To prepare for this trial, the rectangular ponds (125 m × 32 m) were drained and dried for at least three weeks prior to filling. In ponds not completely drained, feral fish (*Tilapia* sp. and *Gambusia* sp.) were killed by chlorination.

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TABLE 1. *Proximate composition of commercial pellets used in study (Stanley and Moore 1983).*

	% Dry matter basis
Dry matter	90.6
Crude protein	25.9
Ether extract (fat)	4.0
Ash	10.0
Acid detergent fiber	8.2
Neutral detergent fiber	17.0
Permanganate lignin	2.3
Cellulose	5.9

one paddlewheel pond (#3). Shrimp mortality in the other two paddlewheel ponds was averted by using tractor-driven paddlewheels to maintain sufficient DO. Pond 3 production, survival, and crop value data were not used to calculate paddlewheel pond production, survival, and crop value.

Over a three week period ending 8 October, shrimp were harvested with a 15 cm shrimp pump. Ponds from each treatment were alternately harvested to reduce time biases. Mean body weights at harvest for each pond were determined by measuring individual body weights of 100 randomly sampled shrimp from each pond. Pond mean body weights were averaged within treatments and are presented in Fig. 1 at H on the x-axis to indicate harvest.

Statistical differences among treatments for various parameters were tested by one-way ANOVA using Systat (Wilkinson 1986). Crop value was calculated for each pond as total harvest weight per pond times the price per kg of shrimp based on actual prices received by Amorient at the time of these trials.

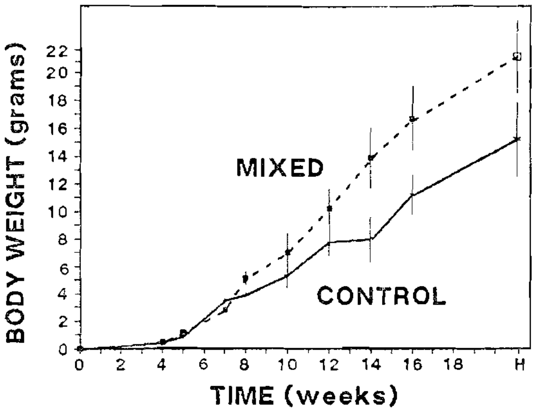

FIGURE 1. *Mean shrimp growth in paddlewheel and control ponds. Points are mean values (±SEM) of three replicate ponds per treatment. H indicates size at harvest which was not on the same day for all ponds.*

Results

Ponds differed little in physical-chemical parameters. Although higher average DO tended to occur in paddlewheel ponds (9.7 vs. 8.9 mg/L), treatments were not significantly different (Table 2). There was no difference between treatments for mean secchi depth (Table 2) over the course of the trial. Control ponds were significantly ($P < 0.05$) warmer than paddlewheel ponds (28.5 vs. 28.3 C), but it is doubtful that this small difference in pond temperature affected shrimp growth or production. These differences suggest that paddlewheels may actually have a cooling effect on ponds. There was no significant difference in salinity between treatments.

Significantly less water was used in pad-

TABLE 2. *Mean, standard error of the mean (SEM), minimum (min) and maximum (max) of dissolved oxygen (DO) concentration (mg/L), secchi depth (cm), temperature (C), and salinity (ppt) in paddlewheel and control ponds from April–October, 1986.*

	DO		Secchi		Temperature		Salinity	
Treatment	Pwheel	Control	Pwheel	Control	Pwheel	Control	Pwheel	Control
Mean	9.7	8.9	46.6	46.5	28.3[a]	28.5[b]	28.5	28.3
SEM	0.3	0.3	1.8	0.7	0.1	0.1	0.6	1.0
Min	2.8	3.6	20.0	20.0	23.0	23.5	20.0	18.0
Max	19.4	20.0	100.0	100.0	32.0	33.0	34.0	34.0

[a,b] Significantly different means ($P < 0.05$).

dlewheel ponds than in control ponds (0.8% exchange/d vs. 2.2% exchange/d). Water was added to ponds to either compensate for evaporation or when dissolved oxygen levels were less than 7.5 mg/L. If paddlewheels increase evaporation rates, as suggested by lower pond temperatures, then paddlewheel ponds should use more water to maintain constant salinities. Since lower water use was observed in paddlewheel ponds, factors other than evaporation must have contributed to water use.

Water was also added to ponds when DO levels fell below 7.5 mg/L in the afternoon. In paddlewheel ponds, DO was less than 7.5 mg/L 14% of all monitored days, while in control ponds DO was less than 7.5 mg/L 24% of all monitored days. Farm pond managers reported that control ponds were substantially less stable and more likely to have DO problems than paddlewheel ponds. Lower water exchange rates in paddlewheel ponds indicate that continuous paddlewheel operation is an effective alternative to water exchange for maintaining minimum DO levels in shrimp ponds.

Whereas shrimp growth rates were not significantly different during weeks 0–12, a strong trend of faster growth in paddlewheel ponds was evident from week 8 onward (Fig. 1). At week 14, mean shrimp weights and growth rates were greater ($P < 0.05$) in paddlewheel ponds (13.9 g; 0.99 g/wk) than in control ponds (8.0 g; 0.57 g/wk). In one paddlewheel pond, shrimp grew from 2.3 to 20.9 g between weeks 7 and 16. This is an average growth rate of 2.1 g/wk, which exceeds any previously published growth rates for *P. vannamei* in earthen ponds (reviewed in Wyban et al. 1987b). In nature, *P. vannamei* growth rates can approach 1.5 g/wk at densities of 2–3 animals/m^2 (Menz and Blake 1980). In South Carolina *P. vannamei* production trials, with continuous paddlewheel use and stocking densities of 45 postlarvae/m^2, mean shrimp size at 14 weeks was about 12 grams (Sandifer et al. 1987).

Mean duration of two treatments was not different and averaged 150 ± 2.5 days. Feed conversion ratios were also not different between treatments and averaged 3.5 ± 0.3 overall (i.e., kg feed added/kg shrimp harvested). Maximum feed rates reached 70 kg/ha/d in both treatments. These rates are high relative to commercial earthen ponds in Hawaii without aeration. In freshwater prawn ponds, feed rates average 36 kg/ha/d (Corbin et al. 1983).

Survival was not significantly different between treatments and averaged 55 ± 8.5%. Shrimp weights at harvest averaged 21.2 ± 2.6 g in paddlewheel ponds and 15.3 ± 2.6 g in control ponds (Table 3). Average production in paddlewheel ponds was 2,852 ± 222 kg/ha compared to only 2,061 ± 558 kg/ha in control ponds (Table 3).

Discussion

The nature of the paddlewheel effect is complex. Pond oxygen levels were more stable in paddlewheel ponds, and there was a trend toward higher DO levels in paddlewheel ponds. In freshwater catfish ponds, supplemental paddlewheel aeration increased fish production from 1,400 kg/ha in control ponds to 5,390 kg/ha in paddlewheel ponds (Hallerman and Boyd 1980). These authors attributed the effect to increased DO in paddlewheel ponds.

Another factor which could contribute to the paddlewheel effect is increased pond mixing and destratification. Wind-induced mixing of ponds in this experiment may have limited differences in shrimp growth and yields between paddlewheel and control ponds. The Amorient site is an extremely windy location (average wind speed during the experiment was eight knots). On seven occasions, all six ponds were monitored for temperature and oxygen stratification and none was observed. Paddlewheels may have an even more dramatic effect on shrimp growth and yields in ponds in calm locations.

A third factor possibly involved in the paddlewheel effect is removal of dissolved organic carbon (DOC) from pond water via foam fractionation. As paddlewheel-in-

TABLE 3. *Mean and standard error of mean (SEM) of shrimp growth, trial duration, feed conversion ratio, survival, and individual body weights at harvest and production in paddlewheel and control ponds.*

Treatment	Paddlewheel	Control
Growth rate (g/wk)		
Mean	1.19	0.75
SEM	0.15	0.09
Duration (days)		
Mean	147	152
SEM	2.9	8.1
Feed conversion ratio		
Mean	3.2	3.8
SEM	0.4	0.3
Survival (%)		
Mean	55.6[a]	54.6
SEM	8.9	8.1
Individual body weight at harvest (g)		
Mean	21.2	15.3
SEM	2.6	2.6
Production (kg/ha)		
Mean	2,852[a]	2,061
SEM	222	558

[a] Data from pond 3 not included.

TABLE 4. *Crop value, paddlewheel operating costs and net crop value in paddlewheel and control ponds.*

Treatment	Paddle-wheel	Control
Crop value	$13,719	$9,111
Paddlewheel costs per pond:		
Water-use savings	−84	
Power costs	403	
Paddlewheel (@ 3 yrs)	231	
Extra feed	156	
Total added costs per pond	706	
Net crop value	$13,013	$9,111

duced air bubbles pass through pond water, the surface active fraction of DOC is absorbed onto bubble surfaces, producing foam at the air-water interface (Spotte 1979). Foam generation by the paddlewheels was observed daily in this study. When unaerated shrimp ponds received emergency paddlewheel aeration, large quantities of foam (e.g., 20–30 m^3 in a 0.4 ha pond) were generated (Wyban, unpublished observation). It is not known whether high DOC levels developed in the control ponds or whether DOC affects shrimp growth.

Although alternative means may achieve each of these effects separately, paddlewheels provide all three. In addition, paddlewheels are the most efficient method of aeration in ponds (Boyd 1988).

Because ponds with paddlewheels produced larger (thus, higher value) shrimp and greater production per pond, crop value amplified differences between paddlewheel and control ponds. Mean crop value for paddlewheel ponds was $13,719 per pond and only $9,111 per pond for control ponds (Table 4). This represents a difference in crop value of $4,608 per pond. Total per pond cost of paddlewheel operation is the sum of amortized and maintenance costs of two paddlewheels per pond ($230), electricity costs ($403), additional feed costs ($156) and cost savings in water use (−$84) which together totalled $706. Subtracting these additional costs from the increased crop value in the paddlewheel ponds yields an increase of $3,902 in net crop value per pond. Thus, net crop value was increased 42% as a result of using paddlewheels in this study.

In conclusion, use of paddlewheels in commercial earthen shrimp ponds appears to improve pond conditions, resulting in decreased water use, increased shrimp growth rates, increased total production, and increased net crop value. The combination of these factors supports what appears to be well understood in Taiwan: use of paddlewheels in commercial shrimp production ponds increases profitability.

Acknowledgments

The able assistance of Thomas Guevera, Quirino Olegario, Deborah Shiraishi, James Sweeney, and William Richards is greatly appreciated. Betty Sonoda word processed the document. Funds were provided by the U.S. Marine Shrimp Farming Program, United States Department of Agriculture Grant No. CSRS-2-2532.

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