The Effects of Water Depth and Circulation on the Water Quality and Production of *Penaeus monodon* in Earthen Ponds*

KENT E. CARPENTER[1]
ARLO W. FAST[1]
VALERIANO L. CORRE
JAMES W. WOESSNER[1]
ROSY L. JANEO
BrackishwaterAquaculture Center
University of the Philippines in the Visayas
Leganes, Iloilo, Philippines

[1] *Present address: Hawaii Institute of Marine Biology*
University of Hawaii
Honolulu, Hawaii 96822 USA

CARPENTER, K.E., A.W. FAST, V.L. CORRE, J.W. WOESSNER and R.L. JANEO. 1986. The effects of water depth and circulation on the water quality and production of *Penaeus monodon* in earthen ponds, p. 21-24. *In* J.L. Maclean, L.B. Dizon and L.V. Hosillos (eds.) The First Asian Fisheries Forum. Asian Fisheries Society, Manila, Philippines.

Abstract

Successful high intensive shrimp grow-out schemes typically use deep ponds (1-2 m) together with aeration/circulation. Little is known, however, why deep ponds are more productive than shallow ponds. It is important to understand the water quality and production dynamics of ponds of different depths to develop appropriate shrimp culture methods. The effects of water depth and circulation on the production of the giant tiger shrimp, *Penaeus monodon*, in 0.1-ha earthen ponds were tested in a 3 x 2 factorial experiment, with three depth treatments (0.5, 1.0 and 1.5 m) and two circulation regimes (daytime circulation and uncirculated). Stocking density was 4 postlarvae/m^2. Production and survival were determined after five- and four-month culture periods during the dry and wet seasons, respectively, in 1985. Water circulation positively influenced primary productivity, decreased the surface temperature, and reduced stratification of temperature and dissolved oxygen. Water depth significantly affected almost all water quality parameters, the deeper ponds producing shrimp of significantly larger size. However, there were no treatment effects on shrimp production due to an inverse relation of survival and average size. It can be said that water depth and circulation profoundly affect the water quality of brackishwater shrimp ponds, but that the effects on shrimp production are not apparent at the stocking density used in this experiment. Further tests at higher stocking densities are necessary to establish the causal relationships of water depth, survival and average size of shrimp.

Introduction

One factor that contributes largely to the success of semi-intensive and intensive penaeid grow-out schemes is effective water management. There are several water management techniques for penaeid pond culture, all involving varying water depths and circulation/aeration methods (Kungvankij 1985). Average pond water depth and water movement are two important factors that can affect numerous aspects of pond environments. These include effects on the heat budget, thermal and chemical stratification, minimum oxygen concentrations and ultimately the growth and survival of the shrimp.

The Taiwanese are well known for their outstanding achievements in the development of penaeid pond grow-out systems (Liao 1985). These schemes depend heavily on deep water and substantial circulation/aeration and yet there appears to be a lack of basic information regarding the environmental dynamics of these systems. It is important to understand these pond dynamics in designing appropriate grow-out strategies for shrimp in countries with economic situations different from those of Taiwan. For example, energy intensive systems are not as prohibitive in Taiwan because of low energy costs, whereas energy costs in the Philippines often make intensive culture systems uneconomical. Furthermore, Taiwanese shrimp ponds are usually deep, as much as 1.8 m, (Fast et al., unpublished data) while the majority of brackishwater fishponds in many Southeast Asian countries are as shallow as 0.5 m. It maybe improbable, therefore, for the shallow ponds in the Philippines to be used for intensive shrimp grow-out using Taiwanese techniques. The purpose of this study was to evaluate the effects of different water depths and water circulation regimes on water quality as well as growth and survival of the giant tiger shrimp, *Penaeus monodon*, in earthen ponds.

The Pond Dynamics/Aquaculture CRSP gratefully acknowledges the Asian Fisheries Society for allowing this paper to be reproduced in CRSP Research Reports. This paper originally appeared in the Proceedings of the First Asian Fisheries Forum, Manila, Philippines, 1986, pp. 21-24.

Materials and Methods

A 3 x 2 factorial design was used to test the effects of depth and circulation on water quality and shrimp production in earthen ponds. Eighteen 0.1-ha earthen ponds were used, with depth treatments of 1.5, 1.0 and 0.5 m. Three ponds in each depth treatment were subjected to artifical circulation during the daytime (6 a.m to 5 p.m.), while the other three were not. Circulation was done by a device consisting of a 1/8-hp electric motor, driving a submerged 46-cm fan-type impellor at 86 rpm similar to those described by Fast et al. (1983).

The experiment was conducted twice, with a 150-day grow-out during the dry season (December 1984-April 1985) and a 120-day grow-out during the wet season (August-December 1985). The ponds were prepared by draining, drying, applying agricultural lime and chicken manure at 2 t/ha to each, and then gradually flooding to grow benthic algae *(lablab)*. In each trial, *P. monodon* postlarvae were stocked at 4/m^2. The average weight of initially-stocked postlarvae during the dry season was 4.7 mg and during the wet season 2.1 mg. Feeding rate was at 10% average body weight during the second month of grow-out, 8% during the third month and 4% during the final month. Formulated feeds were not applied during the first month. Water exchange was twice a month, depending on the occurrence of spring tides, at a rate of 50% of total water volume each time. Additional water exchange through pumping was sometimes necessary during the later stages of grow-out because of low dissolved oxygen levels. Emergency aeration with a 1/2-hp paddle wheel aerator was also used occasionally.

Salinity was measured daily with a refractometer. Dissolved oxygen and temperature at varying depths at different times of the day were measured three times a week with a YSI oxygen meter. Visibility with a secchi disk and pH with a Corning pH meter were also measured three times a week. Chlorophyll *a* concentrations, un-ionized ammonia, nitrates, nitrites, dissolved orthophosphate and plankton levels were monitored twice a month. Chlorophyll *a* concentrations were determined according to Lind (1974). Concentrations of un-ionized ammonia, nitrates, nitrites and dissolved orthophosphate were determined with the methods of Strickland and Parsons (1976). Un-ionized ammonia and dissolved orthophosphate were analyzed by the phenol hypochloride and ascorbic acid methods, respectively. Phytoplankton were counted with a hemocytometer, zooplankton with a Sedgewick rafter. Prawn growth was monitored once a month by weighing a subsample of shrimp from each pond.

The SYSTAT package (Wilkinson 1984) was used for all statistical analysis. Water quality data were averaged monthly corresponding to intervals between the shrimp sampling dates. A two-way ANOVA factorial analysis with replication per sampling was done on the water quality parameters. A stepwise multiple regression analysis was done to determine which of the variables best predicted the average size of shrimp per sampling (i.e., the growth of shrimp). All the water quality variables listed in Table 1 were initially entered in the model (both alpha to enter and alpha to remove levels were $p = .15$).

The analyses of growth and harvest data for the dry season are not presented here because the large number of finfish intruders in the ponds made it difficult to assess treatment effects on *P. monodon* alone. During the wet season, ponds were treated with an ichthyocide (teaseed cake) controlling intruders to negligible levels (Minsalan and Chiu, this vol.). A two-way factorial ANOVA was done on the wet season harvest data.

Results and Discussion

Most water quality values changed significantly during the grow-out period, with the exception of un-ionized ammonia concentrations (Table 1), which were also unaffected by any of the depth or circulation treatments. It is possible that ammonia nitrogen is readily metabolized in brackishwater ponds and rarely attains high concentrations. Seasonal weather changes are most probably the reason for changes in pond temperature and salinity during the grow-out period. Changes in productivity and nutrient concentrations with time were perhaps due to an increased feed loading during the grow-out. These changes were exemplified by increases in secchi disk depth, dissolved oxygen, chlorophyl concentration, phytoplankton, zooplankton, nitrates, nitrites and reactive phosphorus.

Most of the water quality parameters were significantly affected by the depth treatments (Table 1). Those variables related to productivity (secchi disk depth, morning and afternoon oxygen concentrations, Chlorophyll *a*, phytoplankton and zooplankton) and nutrient concentrations (nitrites, nitrates and reactive phosphorous) were significantly higher in the shallower pond. This is undoubtedly due to lesser volumes of water in the shallow ponds, since all ponds received equal feed applications. Cole and Boyd (1986) have shown that average concentrations of such water quality parameters as Cholorphyll *a*, nitrite nitrogen and chemical oxygen demand increase with increasing feeding rates. A similar relationship is expected with equal feed applications to ponds with decreasing water volumes. The shallow ponds also proved to be less stable environments with regard to diurnal temperature fluctuations. These ponds had significantly higher afternoon and significantly lower morning temperatures (Table 1).

There were few significant treatment effects due to circulation. Daytime circulation did, however, appear to lower the surface temperature of the pond. There was significantly lower afternoon temperatures during the dry season and significantly lower morning temperatures during the wet season in circulated ponds. Daytime circulation also appeared to increase primary productivity as Chlorophyll *a* concentrations were higher in circulated ponds during the wet season. This increase in primary productivity due to circulation is also evidenced by higher dissolved oxygen concentrations in the afternoons. Daytime circulation also substantially decreased thermal and oxygen stratification in the pond throughout the diurnal cycle.

In both trials, the average shrimp size per sampling was significantly higher in the deeper ponds (Table 1). The faster growth of shrimp in the 1.5-m and 1.0-m deep ponds than in the 0.5-m deep ponds during the wet season trial is illustrated in Fig. 1. During the wet season, shrimps were larger in circulated pond water and significantly larger in circulated water in deeper ponds (Table 1). Growth, therefore, appears affected by both water depth and circulation.

Depth was retained by the stepwise regression procedure as a significant indicator of shrimp growth during the wet season (Table 2). Salinity was also retained in the model in view of its importance to the growth of *P. monodon*. Various other water quality parameters were also retained in the model which reflect the productivity (morning and evening dissolved oxygen and phytoplankton densities) and feeding rate (ammonia and nitrates) influences on shrimp growth.

There were significant effects of water depth on both size and survival of *P. monodon* (Table 3). These dependent variables were, however, inversely related. Size was larger but survival was lower in deep ponds. A regression of size versus survival was significant ($y = 125.3 - 1.8x$, probability regression F ratio = .002). This inverse relationship explains the lack of significant treatment effects on total production (i.e., the deeper ponds had larger but fewer shrimp while the shallower ponds had smaller but more numerous shrimp). An analysis of covariance of size of shrimp versus the depth treatments with survival as covariate showed no significant ($p = 0.477$) depth effects on size of shrimp.

It is difficult to evaluate the effects of water depth on the growth of *P. monodon* in view of the inverse relation of size and survival during the wet season grow-out period. It is possible that survival is dependent on water depth and that shallow ponds would be expected to have higher survival, given approximately equal feeding rates in all ponds. If this is so, and if size is inversely and causally related to survival, then it may not be necessary to use deep ponds to obtain a particular yield level. It is also possible, however, that the survival patterns observed during the wet season trial are due to some factors unrelated directly to the depth treatments.

If water depth, average size and survival are causally related as the results from the wet season trial indicate, this scheme may be useful only at the stocking density used in this study ($4/m^2$). It is clear that depth and circulation affect many aspects of the pond environment. It may be that at stocking densities for more intensive penaeid culture, these water quality differences could substantially influence overall production. It would therefore be useful to test these treatment effects at high stocking densities.

Acknowledgements

The faculty and staff of the University of the Philippines in the Visayas, College of Fisheries, Brackishwater Aquaculture Center (BAC), and the regular Cooperative Research and Support Project Employees at the BAC who participated in this project are thanked for their efforts. In particular, the computer expertise and data management skills of Mr. Victor Emmanuel J. Estilo were indispensable. Ms. Jane J. Jaspe and Ms. Julie M. Jomen are gratefully acknowledged for their administrative support of the experiment and in the preparation of this paper. The comments and suggestions of Mr. Terence Barry and Dr. Kevin Hopkins on an earlier version of this paper are appreciated. This research was made possible through the USAID Aquaculture Collaborative Research and Support Program.

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*Contribution Number CRSP 86:1.

Table 1. Water quality parameters and growth of prawn.

Variable	Dry season Time	Dry season Depth	Dry season Circ	Dry season Depth xCirc	Wet season Time	Wet season Depth	Wet season Circ	Wet season Depth xCirc
Secchi depth	**	**			**	**	**	*
Temp. A.M.	**	**			**	**	–*	
Temp. P.M.	**	–**	–**	*	**	–*		
D.O. A.M.	**	**		*	**	**		*
D.O. P.M.	*	–**	**	**	*	–**	*	*
Salinity	**	–**			**			
Ammonia								
Nitrates	**	–*			**			
Nitrites	**	–**			**	–**		
Phosphorous	**				**	–**		
Chlorophyll a	**	–**			**	–**	*	
Phytoplankton	**	–*			*			
Zooplankton	**	–**			*			
Average size	**	**		*	**	*	*	*

**Significant at P < .001; *Significant at P < .05; Blank—not significant.
—Higher values in shallower ponds or higher values in ponds without circulation.

Table 2. Indicator variables for prawn growth during the wet season.

Coefficient	Variable	Probability*
	Dependent = log (average weight)	
2.663	Constant	.000
0.610	Time	.000
0.012	Depth	.000
−0.229	D.O. A.M.	.000
0.052	D.O. P.M.	.015
−0.109	Salinity	.000
2.504	Ammonia	.005
0.398	Nitrates	.000
0.000	Phytoplankton	.111

*2 tail tests.

Table 3. Average weight, survival and total production per treatment, wet season trial.

Treatment Depth (m)	Circulation	Average weight (g)	% Survival	Total production (kg/ha)
1.5	Yes	33.2	65.9	873.3
1.5	No	33.9	57.3	777.6
1.0	Yes	35.7	58.8	829.8
1.0	No	28.2	77.0	875.9
0.5	Yes	28.4	78.3	887.9
0.5	No	26.3	80.5	861.1

Two-Way factorial ANOVA: Probabilities associated with the F-ratio

Treatments	Average weight	Survival	Total production
Depth	.018*	.009*	.775
Circulation	.076	.335	.658
Depth x Circ.	.125	.047*	.597

* = significant.

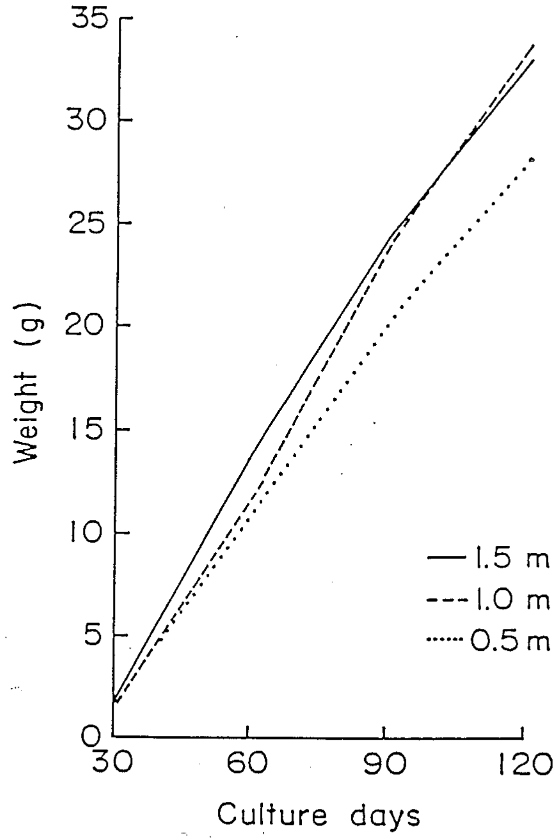

Fig. 1. Growth of prawn per depth treatment for wet season.

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February 8, 1988 **CRSP RESEARCH REPORTS 88-6**