Briggs, M.R.P. and Brown, J.H., 1991. Intensive rearing of postlarval *Penaeus monodon* in concrete nursery tanks.

ABSTRACT

A system of twelve 25 m^3 concrete nursery tanks was used to investigate the parameters affecting the intensive nursery rearing of postlarval (PL) *Penaeus monodon*. The effects of habitats, substrates, dietary formulation and feeding rate on PL_{15} shrimp performance and system water quality were studied in two trials.

Results indicated that with water exchange at 20%d^{-1}, the maximum stocking density of between 500 and 1,000 PLm^{-2} achievable in the absence of aeration could be increased to at least 2,000 m^{-2} with aeration. Increased stocking density led to concomitant increases in shrimp production (to a maximum of 11.5 g $m^{-2}d^{-1}$), but decreases in individual growth rate and survival. Substrate, consisting of a 10 cm layer of riverine sand provided no advantage, but habitats comprising vertical mesh panels were beneficial to survival and production at high stocking density. Analysis of the optimum feeding rates of a pelleted diet revealed that PL 15 to 50 would consume a maximum of between 30 and 60% (depending upon postlarval age) of their wet body weight per day at four feeds per day. Increasing the feeding rate up to this level however, resulted in problems with system water quality. A change in the reference diet to one containing higher levels of lipid, protein and dietary energy was inversely correlated to shrimp production.

INTRODUCTION

Previous trials in this series were conducted in the concrete tank system at the Tinsulanonda Songkhla Fisheries College (Briggs and Brown, in prep.). These trials tested the effects of low-range stocking density and net panel habitats on water quality and performance of postlarval *Penaeus monodon* in the absence of aeration. Results showed that shrimp growth, survival and feeding efficiency were inversely proportional to stocking density. However, total weight gain and production (yield) were directly related to density due to the increased number and biomass of shrimp at higher densities. An additional source of aeration proved to be necessary at densities of about 1,000 PLm^{-2} to prevent low dissolved oxygen (DO) levels resulting in shrimp mortality. The current trials were designed to establish the roles of net panel habitats, sand substrates, dietary formulation and feeding rate at increased stocking density in the presence of aeration.

Habitats:

Published literature on the effects of habitats on shrimp nursery production show conflicting results. A wide range of artificial habitats have been used in nursery trials with shrimp and prawns. Habitat inclusion is thought to stimulate natural productivity, provide shelter for moulting animals and hence increase growth,

survival and feeding efficiency. A previous trial in this series (Briggs and Brown, in prep.) showed that an increase in the wetted surface area (WSA) of the concrete tanks from 50 m^2 by 40, 80 and 160% using vertical mesh panels in the absence of aeration stocked at 500 $PL_{15}m^{-2}$ did not significantly affect either water quality or shrimp performance.

Substrates:

Mud/earth substrates are thought to be responsible for the increased natural productivity of earth pond and pen cage nurseries. Polythene lined ponds with a 20-30 cm layer of sand substrate have been tested (Issar *et al.*, 1987; Sandifer *et al.*, 1987), but no evaluation of substrate preference or type has been published in the literature. Commercial concrete tank nurseries in Thailand, however, often utilise a 5-10 cm layer of coarse grained riverine sand, suggesting that it increases nursery productivity.

Dietary formulation:

Little has been published on the effects of dietary formulation on postlarval shrimp production under field conditions. Most work has been conducted in the laboratory, where formulated diets provide the only nutrition for the shrimp, but the additional role of natural feeding under field conditions has been poorly studied. Most studies on the nursery rearing of shrimp in the field have used either fresh or frozen natural diets (Apud *et al.*, 1979, Parado-Estepa, 1988, De La Pena *et al.*, 1985, Smets *et al.*, 1985, Issar *et al.*, 1987). Other authors have used high quality (>50% protein) formulated pellets (Thai farmers, pers. comm.; Tabbu, 1985; Sumeru and Nur, 1986; Sturmer and Lawrence, 1986, 1987a,b, 1988a,b; Issar *et al.*, 1987; Parado-Estepa, 1988), but have rarely quoted the dietary formulations or tested different formulations under field conditions.

Feeding rate:

The effects of feeding rate and frequency on postlarval shrimp production have been little researched. In the laboratory, frequent feeding has been shown to improve the growth of shrimp, prawns and fish (Sedgewick, 1979; Subramanian and Krishnamurthy 1986). In the field, various authors have used different feeding frequencies, but comparison between regimes are scarce. The optimum feeding rate for postlarval shrimp held in nurseries has not been researched. Commercial nurseries in Thailand feed pelleted diets at 25% wet body weight d^{-1} between PL_5 and PL_{15-20}. Aquacop (1985) suggest using a rate of 30% for penaeids from PL_3 to PL_{30}. Mock *et al.* (1973) fed Tetra Marin feed once or twice daily at 94% body weight d^{-1}, decreasing to 37%d^{-1} as the shrimp grew. Sandifer *et al.* (1987) fed a 40% protein pellet once daily at 10% body weight d^{-1}, supplemented with fresh squid three times per week. Issar *et al.* (1987), fed pelleted and fresh diets *ad libitum* to juvenile *P. semisulcatus*, while Apud *et al.* (1979) reduced the feeding rate of fresh chopped mussel fed to *P. monodon* in nursery ponds from 100% wet body weight d^{-1} for PL_{4-20} to 20%d^{-1} for PL_{20-30}.

MATERIALS AND METHODS

Experimental System:

The concrete tank system comprised 12 uncovered tanks 10m long, 2.5m wide and 1.3m deep. The tanks had sloping bottoms to facilitate harvesting and the water depth averaged 1m. Tanks were thus 25 m^2 in bottom area, 50 m^2 in wetted surface area (WSA) and contained 25 m^3 of water. Water was supplied continuously at 20% tank volume d^{-1} (3.5 $l.min^{-1}$) per tank initially, rising to 40% (7.0 $l.min^{-1}$) towards the end of the trials where necessary in order to maintain water quality. In contrast to previous trials in this system, trial 1 in this series was aerated with six airstones, each supplying 0.16 $l.s^{-1}$, a total of 1 $l.s^{-1}$ of air to each tank for 24 $h.d^{-1}$. The level of aeration was increased to 1.75 $l.s^{-1}$ in trial 2 in response to low DO levels towards the end of trial 1.

Habitats consisted of three 10m lengths of 1m wide, 1mm nylon mesh netting, providing an additional 60 m^2 of surface area, an increase of 120% WSA per tank. Habitats were positioned vertically along the longitudinal axis of the tanks. Substrate comprised a 10 cm layer of coarse-grained riverine sand covering the floor of each tank.

Diets and Feeding:

The only food fed (supplementing the limited natural productivity) comprised formulated pellets made and supplied by Aquastar Shrimp Farm, Ranote, Thailand. In trial 1, the reference diet (table 1) was used for all treatments. In trial 2, the reference diet was compared to a test formulation (table 1) incorporating elevated levels of lipid, protein and hence energy, at both low and high (to satiation) feeding rates. All of the diets tested were in two forms, No.1 crumble (0.5-1mm) and No.2 pellet (1-2mm mean pellet size). The two forms of each diet had similar proximate compositions (table 1). Shrimp were fed No. 1 for weeks 1 to 4 and No. 2 during week 5 as the shrimp required a larger pellet.

Diets were fed 6 days per week, 4 times daily (25% of the daily ration per feeding) at the following times: 07.00, 11.00, 15.00 and 19.00h. In trial 1, shrimp were fed at 35, 30, 25, 20 and 15% wet body weight d^{-1} for weeks 1 to 5 respectively, allowing for 5% mortality per week. In trial 2, the reference and test diets were each fed at both a low feed rate and to satiation. Feeding was at 30, 25, 20, 15, and 10%d^{-1} for weeks 1 to 5 respectively at the low feeding rate. Feeding to satiation resulted in feeding rates of 46, 58-62, 42, 40-43, and 28-30%d^{-1} for weeks 1 to 5 respectively. In trial 2, the mortality rate for purposes of feeding rate estimation (9% per week) was based on that found in trial 1.

Feed was broadcast evenly over each tank by hand to allow all shrimp an equal feeding opportunity at the low feeding rate. In trial 2, feeding trays were used to estimate when shrimp were fed to satiation. Feed was broadcast evenly over the tanks and the trays inspected prior to each daily feeding. If a large quantity of feed remained uneaten the feeding rate was decreased and vice versa.

Experimental Animals:

Postlarvae (PL_{15}) were supplied by Aquastar shrimp farm. PLs were delivered to the nursery system in the cool of morning in oxygenated, double plastic bags, part-filled with sea water. Between 3 and 4,000 PL_{15} were stocked per 5l bag for the one hour trip. One representative sample bag was counted on arrival and the shrimp gradually acclimated to the tanks. Trials were initiated on the day following introduction of the postlarvae. Since postlarvae excess to the number required for the trials were ordered, a representative sample of a few hundred were blotted dry, counted, weighed (±0.0001g) and measured (±0.5mm) on the day of arrival to establish the number, mean weight and length of shrimp.

Trial Treatments:

In trial 1, assessing the effects of net habitats and sand substrates, the four treatments stocked at 2,000 PLm^{-2} of tank floor with aeration were:

1; No habitats, no substrates,
2; No habitats, 10 cm sand substrate,
3; 3 habitats (120% increase in W.S.A.), no substrate,
4; 3 habitats, 10 cm sand substrate.

In trial 2, testing the effects of feeding rate and dietary formulation with aeration, the four treatments stocked at 2,000 PLm^{-2} of tank floor with habitats, but no substrate were:

1; Reference diet, low feeding rate,
2; Reference diet, fed to satiation,
3; Test diet b, low feeding rate,
4; Test diet b, fed to satiation.

Water Quality Measurement:

A range of water quality parameters were measured according to the following schedule: twice daily (before the first and third feeds of the day), water from the inflow canal and the bottom of each tank was sampled for dissolved oxygen, temperature, pH, salinity and transparency; and weekly, water from the same sources was filtered and sampled for suspended solids, ammonia, nitrite and total orthophosphate (table 2).

Dissolved oxygen and temperature was measured using a WTW microprocessor OXY96, oxygen/temperature meter (±0.1 $mg.l^{-1}$ and ±1 % saturation DO, and ±0.1 °C). pH was measured with a WTW microprocessor pH95, pH meter (±0.01 units). Salinity was measured with an Atago refractometer (±0.5 $^{\circ}/_{\circ\circ}$). Transparency was estimated by secchi disc readings expressed as depths in cm (±1 cm). Weekly water samples from the canal and each tank were filtered under vacuum in a Buchner flask through pre-weighed Whatmans 7cm GFC filter papers to collect suspended solids. The filter papers were dried to constant weight overnight at 80°C, reweighed and the load of suspended solids (±0.1$mg.l^{-1}$) calculated (table 2). Filtered water samples were immediately frozen prior to analysis for total ammonia,

nitrite and total orthophosphate by standard methods (APHA, 1974) with a JASCO UVIDEC-430B double beam spectro-photometer. The results were expressed in $ug.l^{-1}$ ±0.1 (table 2).

Measurement of Shrimp Performance:

Shrimp performance was measured weekly (on the non-feeding day) for growth in length and weight by taking three samples of 500 shrimp per tank using a standardised netting procedure, blotting dry the shrimp and measuring the lengths of 100 individuals and group-weighing three replicates of 500 to give mean weight. Weighing was performed on a top pan balance accurate to 0.0001g and lengths taken using a measuring board with 1mm divisions (table 3). From these measurements, weekly growth, specific growth rate (SGR), feeding efficiency (food conversion ratio, FCR, and protein efficiency ratio, PER) and production ($g\ m^{-2}d^{-1}$) were calculated (table 3). At the end of each 35 day trial period, the whole population was weighed and three samples of at least 500 shrimp weighed and 100 individually measured to give the mean weight, length and survival rates for each tank (table 3).

PL Quality and Ongrowing Performance:

The stress tolerance (quality) of shrimp both before (PL_{15}) and after (PL_{50}) the nursery trials was measured for each treatment of each trial (Briggs, in prep.) to test the significance of postlarval quality on nursing and subsequent ongrowing.

Statistical Analysis:

Treatment group comparisons of growth, survival, feeding efficiency, production and water quality data were subjected to statistical analysis to test for significant differences at the $P<0.05$ probability level. These analyses were conducted using ANOVA and, where appropriate, Schaffes' multiple range tests (Zar, 1974).

Table 1: Proximate analysis (% dry weight) of diets.

Diet	Reference diet				Test diet	
	Trial 1		Trial 2			
Size	1	2	1	2	1	2
Crude Protein	51.1	49.8	48.9	49.2	52.2	53.0
Crude Lipid	4.2	3.6	7.4	7.2	11.1	11.3
Ash	17.2	17.8	15.8	16.0	17.6	16.8
Fibre	2.2	2.8	2.2	2.8	1.8	1.4
Moisture	11.4	12.0	8.9	10.2	10.2	10.3
Carbohydrate (by difference)	13.9	14.0	16.8	14.6	7.1	7.2
Total Energy $Kcal.g^{-1}$* (mean)	3.87	3.74	4.17	4.07	4.30	4.36
	3.80		4.12		4.33	
P:E ratio (mg $P.Kcal^{-1}$) (mean)	132	133	117	121	121	121
	133		119		121	
Lipid:Cho ratio (mean)	3.31	3.89	2.27	2.03	0.64	0.64
	3.60		2.15		0.64	

* Calculated Total Energy (T.E.) levels of Protein 5.65, Carbohydrate 4.20 and Lipid 9.45 $Kcalg^{-1}$.

Table 2: Mean water quality parameters of trials 1 and 2*.

Trial No.	1	1	1	1	1	2	2	2	2	2
Treatment (see key below)	1	2	3	4	5	1	2	3	4	5
Temperature (°C)	28.8	29.1	29.2	29.1	30.0	29.0	29.0	29.0	29.1	29.9
Salinity (°/$_{oo}$)	32.7	32.7	32.7	32.7	32.1	32.5	32.5	32.5	32.5	31.7
pH	7.97	7.96	7.94	7.96	7.48	8.16	8.03	8.19	8.03	7.82
Dissolved Oxygen (% saturation)	98.2	100.3	100.7	100.7	83.0	97.0	82.8	96.2	84.3	78.0
Dissolved Oxygen ($mg.l^{-1}$)	6.3	6.5	6.4	6.5	4.9	6.3	5.4	6.3	5.5	4.1
Secchi depth (m)	0.64	0.66	0.66	0.65	0.46	0.74	0.66	0.71	0.68	0.61
Total ammonia ($ug.l^{-1}$)	1.7	1.0	1.4	1.0	0.7	2.1	14.1	2.0	17.8	0.4
Nitrite ($ug.l^{-1}$)	6.7	4.8	6.4	3.5	3.3	5.9	10.2	8.2	18.9	3.8
Total phosphorus ($ug.l^{-1}$)	12.2	10.8	8.4	5.3	5.0	79.8	169.7	57.4	165.6	30.8
Suspended solids ($mg.l^{-1}$)	98.8	96.2	99.3	96.3	108.4	89.2	94.9	90.9	90.7	99.4

Treatment Key:

Trial No.	Treat-ment	Sytem	Stocking Density	Diet type	Habitats	Substrates	Feeding Rate
1	1	Tank	2,000 m^{-2}	Reference	0	0	Low
1	2	Tank	2,000 m^{-2}	Reference	0	10cm	Low
1	3	Tank	2,000 m^{-2}	Reference	3	0	Low
1	4	Tank	2,000 m^{-2}	Reference	3	10cm	Low
1	5	Canal	0 m^{-2}	0	0	0	0
2	1	Tank	2,000 m^{-2}	Reference	3	0	Low
2	2	Tank	2,000 m^{-2}	Reference	3	0	High
2	3	Tank	2,000 m^{-2}	Test	3	0	Low
2	4	Tank	2,000 m^{-2}	Test	3	0	High
2	5	Canal	0 m^{-2}	0	0	0	0

* Mean of 3 replicates for whole period of trial.

Table 3: Mean performance of shrimp in trials 1 and 2*.

Trial No.	1	1	1	1	2	2	2	2
Treatment (see key below)	1	2	3	4	1	2	3	4
Initial wt. (g)	0.0024	0.0024	0.0024	0.0024	0.0027	0.0027	0.0027	0.0027
Final wt. (g)	0.2731	0.2595	0.2568	0.3092	0.5106	0.5770	0.5090	0.5085
Final length (mm)	35.3	33.7	35.3	36.3	44.5	45.6	45.3	42.9
Total food fed (g)	7038.0	5838.4	8757.8	8439.4	9907.6	27743.7	9195.6	24880.2
Total protein fed(g)	3550.0	2944.9	4417.4	4256.8	4859.7	13608.3	4836.9	13087.0
FCR	1.30	1.27	1.26	1.25	1.23	2.87	1.26	3.92
PER	1.54	1.56	1.59	1.62	1.66	0.72	1.50	0.50
SGR (% body wt.d^{-1})	13.46	13.35	13.33	13.87	14.96	15.33	14.96	14.96
Survival (%)	40.66	36.94	54.81	45.47	32.41	35.22	29.08	26.19
Production(g $m^{-2}d^{-1}$)	6.08	5.25	7.88	7.85	9.17	11.46	8.30	7.47

Treatment Key:

Trial No.	Treat-ment	Sytem	Stocking Density	Diet type	Habitats	Substrates	Feeding Rate
1	1	Tank	2,000 m^{-2}	Reference	0	0	Low
1	2	Tank	2,000 m^{-2}	Reference	0	10cm	Low
1	3	Tank	2,000 m^{-2}	Reference	3	0	Low
1	4	Tank	2,000 m^{-2}	Reference	3	10cm	Low
2	1	Tank	2,000 m^{-2}	Reference	3	0	Low
2	2	Tank	2,000 m^{-2}	Reference	3	0	High
2	3	Tank	2,000 m^{-2}	Test	3	0	Low
2	4	Tank	2,000 m^{-2}	Test	3	0	High

* Mean of 3 replicates for whole period of trial.

Figure 1
The effect of substrates and habitats on mean survival (+SE) on day 50 of trial 1.

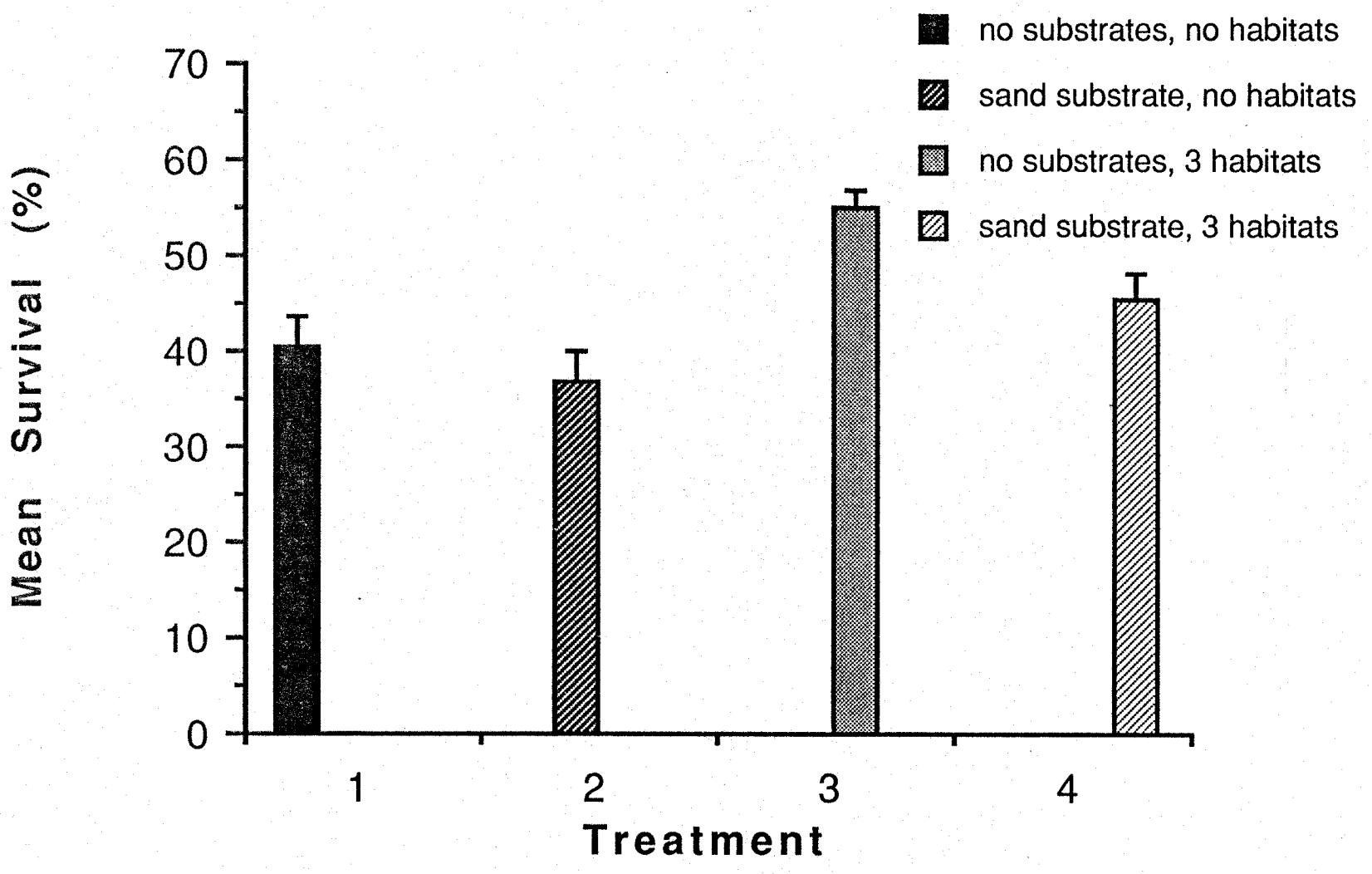


Figure 2

The effect of substrate and habitats on mean production (+SE) in trial 1.

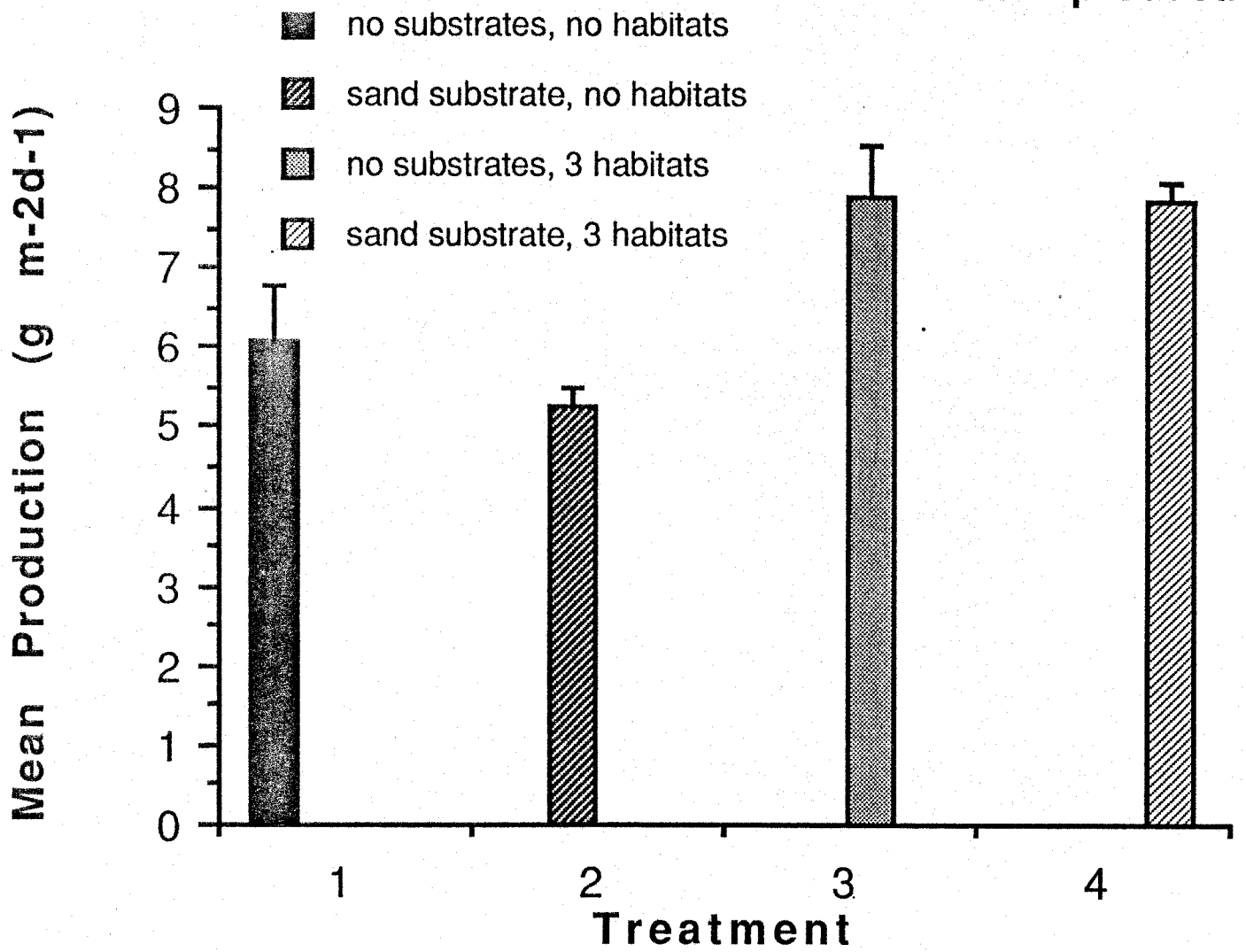


Figure 3

Daily mean dissolved oxygen with time for all treatments in trial 2.

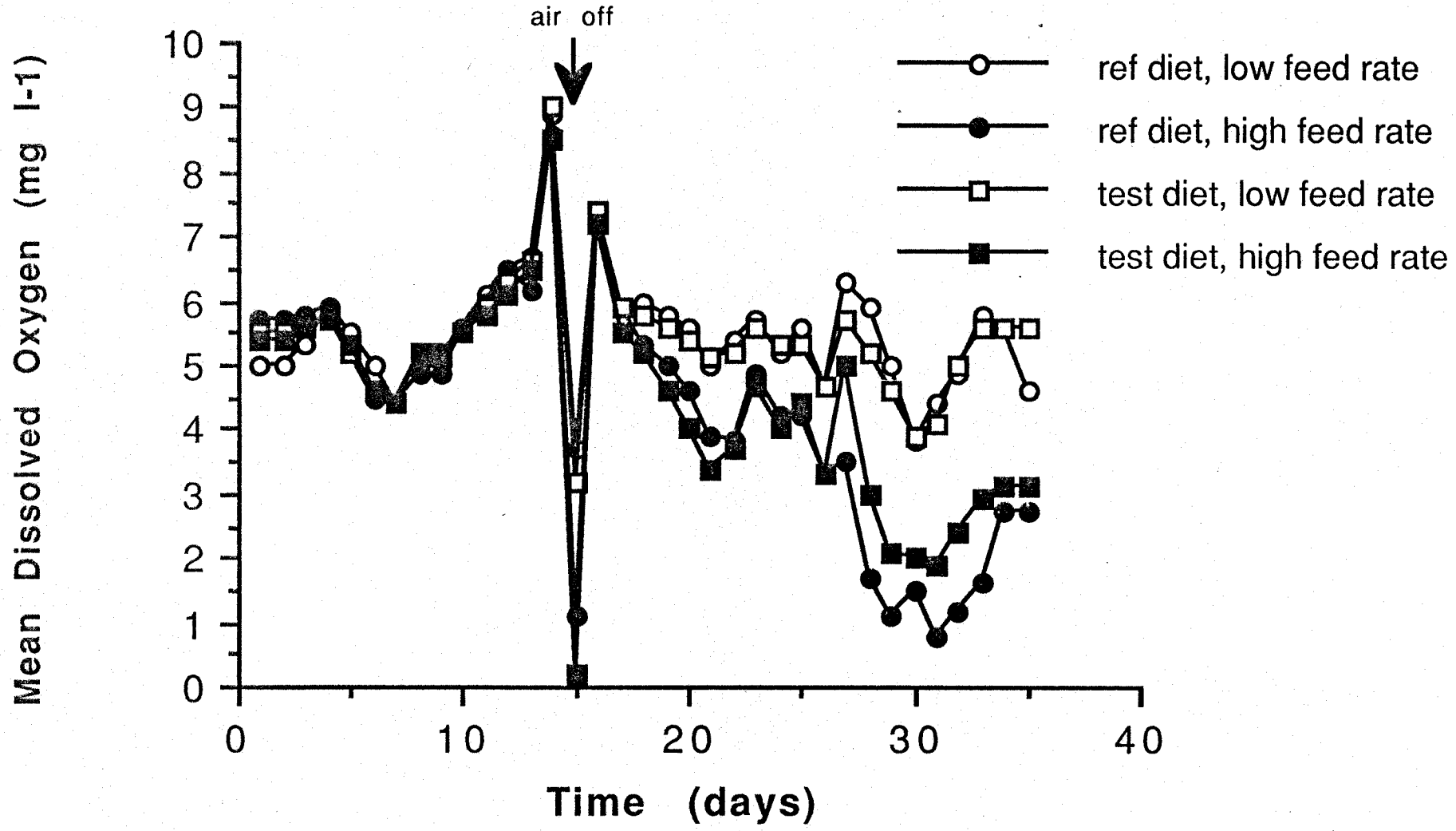


Figure 3

Daily mean dissolved oxygen with time for all treatments in trial 2.

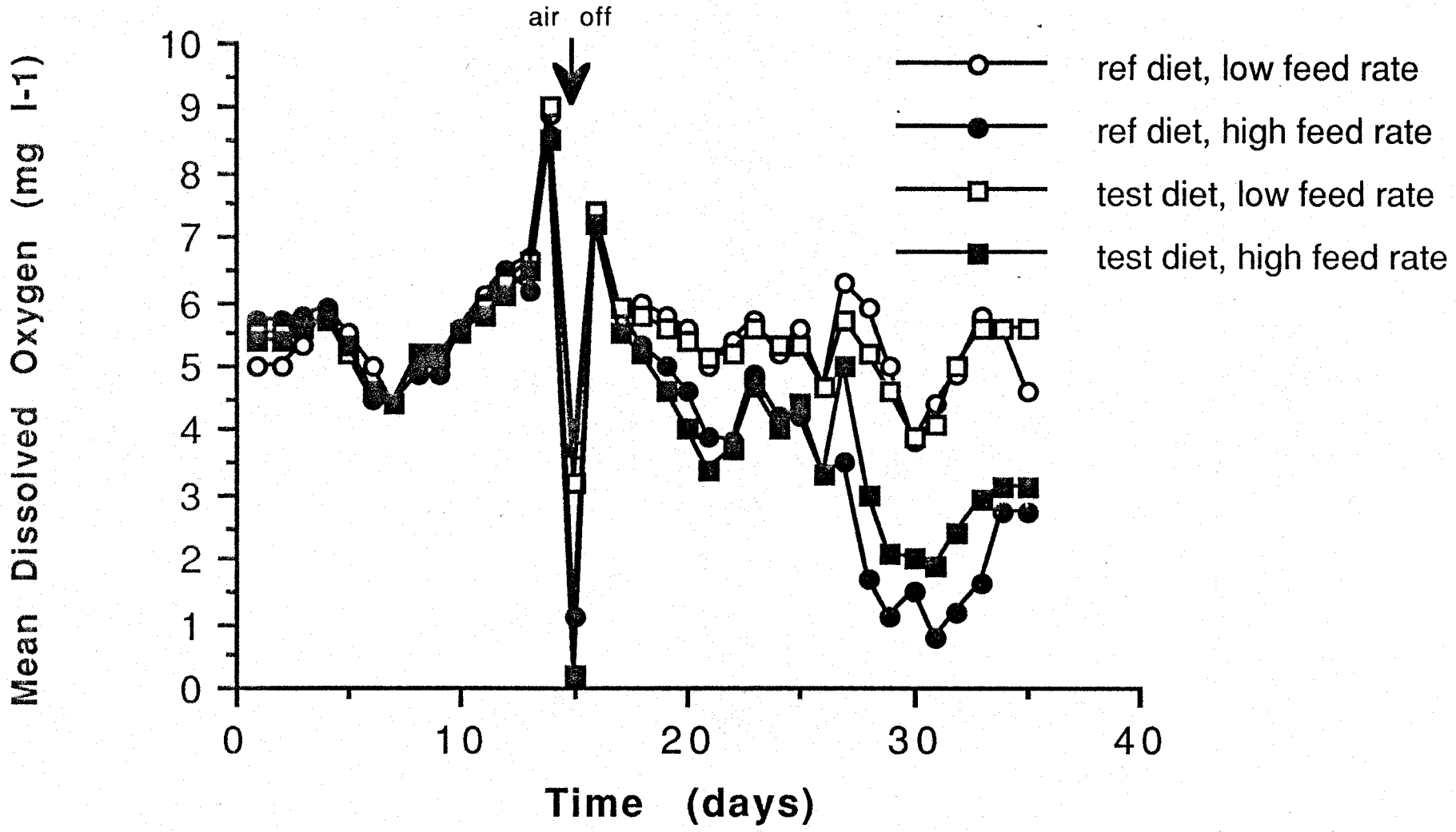


Figure 4

The effect of feeding rate and diet on mean FCR (+SE) on day 50 of trial 2.

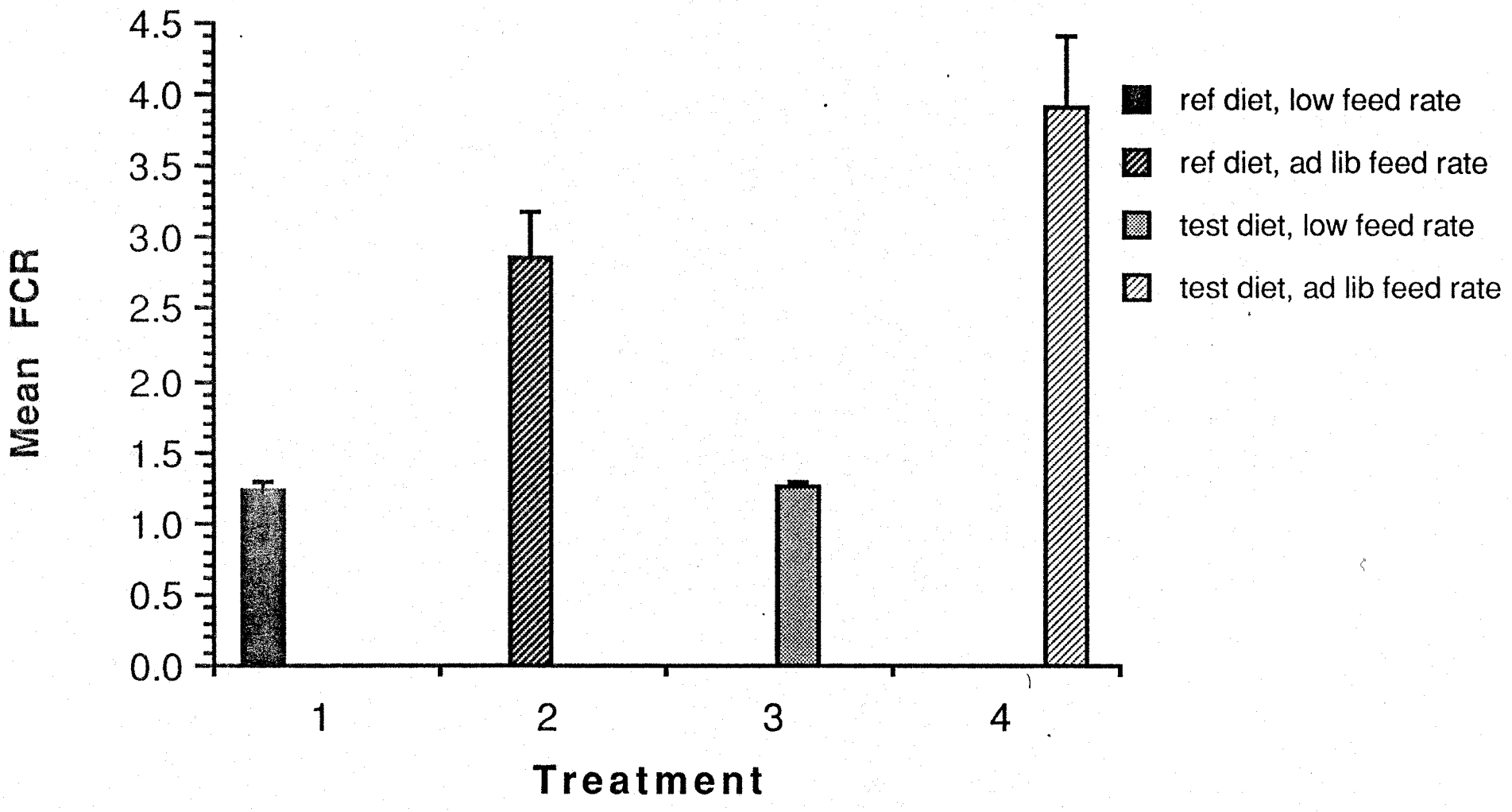
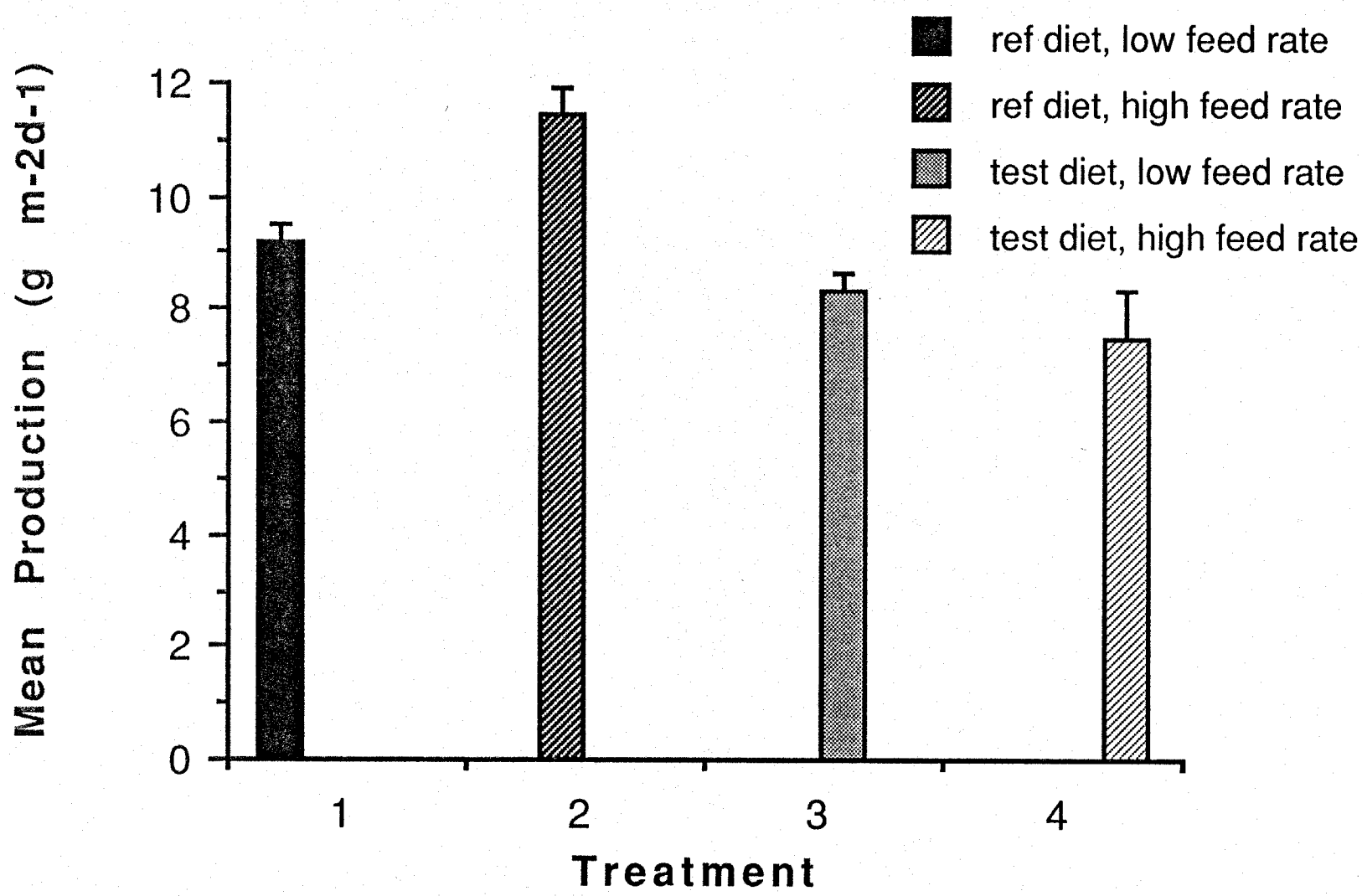


Figure 5
The effect of feeding rate and diet on mean production (+SE) in trial 2.



RESULTS AND DISCUSSION

TRIAL 1: WATER QUALITY

During trial 1 water quality was largely unaffected by the treatments used, i.e. the presence or absence of mesh habitats and/or sand substrates. System water temperature, salinity and pH were stable and close to optimum with no significant differences between treatments (table 2). DO levels were not significantly ($P<0.05$) different between treatments (table 2) and were generally high and stable due to the constant aeration. Algal density measured as secchi depth (SD) was maintained without major blooms or crashes, with no significant differences between treatments (table 2). Dissolved nutrient levels of NH_3, NO_2 and P were not significantly ($P<0.05$) different between treatments, closely followed the levels found in the incoming canal water, but tended to decrease in the presence of habitats and sand substrates (table 2). At a density of 2,000 PLm^{-2} with constant aeration, a water exchange rate of 20%d^{-1} was thus sufficient to remove food and faecal breakdown products before they could accumulate to toxic levels for postlarval *P. monodon*.

TRIAL 1: SHRIMP PERFORMANCE

Production of shrimp during this trial was better than in previous trials in this system due to the higher stocking densities used, facilitated by the maintenance of suitable water quality by continual aeration. The major effect of habitats and substrate in this trial was on shrimp survival. Survival was comparable with that obtained in previous trials (52 to 58%) stocked at only 500 m^{-2}, was significantly ($P<0.05$) increased in the presence of habitats, but decreased with the inclusion of sand substrates (table 3, figure 1). Adding habitats to tanks without substrate increased survival from 41 to 55%, while inclusion of habitats and substrate increased survival from 37 to 46%. Habitats probably improved survival by increasing shelter for shrimp during their delicate and susceptible moulting state, hence reducing mortality due to cannibalism. This result was in contrast to that of previous trials which showed no relationship, suggesting that habitats prevent mortality caused by aggressive interactions between shrimp only at high stocking densities. Decreased survival in the presence of substrate may have been due to substrate siltation by fine sediments drawn into the tanks from the intake canal. Although this problem could possibly be solved by more efficient filtration, the poor performance and additional expense in providing and cleaning the substrate between production runs are likely to make the use of substrates unprofitable.

Shrimp growth rate was largely unrelated to the presence of either mesh habitats and/or sand substrate. Mean final weight (0.26 to 0.31g) and length (33.7 to 36.3 mm) of shrimp was not significantly different between treatments, but was highest for

treatment 4 with both habitats and substrate, probably due to increased natural food availability. However, the increase in mean shrimp weight (table 3) was less than for previous trials in this system stocked at lower densities.

Feeding efficiency in this trial was high, FCRs ranging from 1.25 to 1.30 and PERs from 1.62 to 1.54 (Table 3). Although there were no significant differences between treatments, the presence of habitats tended to enhance, whilst substrates tended to decrease the feeding efficiency. Increased natural food production, stimulated by the habitats was probably responsible for promotion, whilst the silty, anoxic substrate led to reduced feeding efficiency.

Shrimp production was significantly ($P<0.05$) higher with habitats, but lower with substrate (table 3, figure 2), due primarily to increased survival. An increase of 120% in WSA of tanks by habitats increased production (up to 8 g $m^{-2}d^{-1}$) by 50% in the presence of sand substrates, and by 30% without substrates. The high production of shrimp in this trial may have also been related to the high initial quality of postlarvae used, as detected by stress tests (Briggs, in prep.).

Similar results have been recorded by Sturmer and Lawrence (1987a, 1988a), who obtained good growth, survival, production and feeding efficiency of postlarval *P. vannamei* and *P. stylirostris* in concrete nurseries when the WSA was increased 270-300% by habitat inclusion. This effect, they suggested may have been due to stimulation of the natural productivity of the raceways by the habitats. However, Parado-Estepa (1988), was unable to demonstrate a significant benefit from the use of habitats in densely stocked concrete tank nurseries for *P. monodon*, while a previous trial in this system came to similar conclusions at low stocking densities.

The increased expense involved with the construction and maintenance of the net panel habitats which proved unprofitable at the lower stocking density used in a previous trial was negated at higher density, facilitated by the presence of aeration. It would therefore seem profitable to use habitats in such high density nursery rearing.

TRIAL 2: WATER QUALITY

System water temperature, salinity and pH during this trial were stable, close to optimum and not significantly different between treatments (table 2) or from trial 1. Overall, there were no significant differences between diets fed at similar rates for any water quality parameter measured during this trial.

The major effect on water quality during this trial was caused by an electrical failure of the air blower for 24 h. on day 15. Feeding was suspended on this day in an attempt to maintain DO

levels and limit mortality. The consequent lack of aeration caused critical decreases in DO levels on the morning of the failure (table 2, figure 3), especially in treatments fed *ad libitum*. Although DO levels recovered by the following day, shrimp survival had already declined significantly in all tanks. Mean DO levels were high but declined during the trial as the shrimp grew and consumed more oxygen. There was a significant ($P<0.05$) difference between DO levels for treatments of both diets fed at the low feed rate and those fed *ad libitum*, but not between diets. Increased levels of feeding in the treatments fed *ad libitum* also affected the levels of nitrogenous waste products as shown in the significantly higher levels of NH_3, NO_2 and P (table 2). The levels of these nutrients gradually increased until week 4, but were then maintained or decreased to below potentially toxic levels by increasing the daily water exchange rate from 20 to 40%.

TRIAL 2: SHRIMP PERFORMANCE

Despite problems with aeration failure for 24 h, both diets performed well, and better than for previous trials in this system. The major effect of the different feed rates was in the feeding efficiency of the shrimp. At the low feeding rate of both diets feeding efficiency was high and similar to that achieved in trial 1, but significantly ($P<0.05$) better for the reference than the test diet. At the low feeding rate, FCRs of 1.23 and 1.26 and PERs of 1.66 and 1.50 (table 3, figure 4) were obtained for the reference and test diets respectively. Feeding efficiency was, however, very poor at the high feeding rates of both diets. FCRs increased to 2.9-3.9 and PERs declined to 0.7-0.5 for the reference and test diets respectively (table 3). The higher feeding efficiency of shrimp fed the reference diet was probably due to the excessive protein, lipid and hence energy content of the test diet, leading to reduced feed utilization. The poor feeding efficiency of shrimp fed to satiation was probably largely due to low survival as a result of air failure and decreases the economic feasibility of feeding at such high rates.

There were no significant differences between the growth rate of shrimp fed either diet at either rate (table 3). Final mean weight of shrimp fed the reference diet *ad libitum* however, was higher (0.57g) than for all other treatments (0.51g). This may have been due to the better quality of the reference diet and to the higher availability of feed, especially at the reduced shrimp density after the failure in aeration. Mean survival (although low due to air failure) was not significantly different between diets or feeding rates (table 3).

Overall production was significantly ($P<0.05$) higher for shrimp fed the reference diet at the high rate than those fed the test diet where feeding rate made no significant difference. For the reference diet, production increased from 9 to 11.5 g $m^{-2}d^{-1}$ at the low and high feeding rates respectively (table 3, figure 5).

This was largely due to the increased growth and survival rates of shrimp fed at the high rate. For the reference diet, especially when fed at the high rate, this level of production was higher than that achieved in any other trial in this system, despite the air blower failure. This result was probably due to the increased availability of feed, but may also have resulted from the stocking of high quality postlarvae as indicated by stress tests (Briggs, in prep.).

Although the culture conditions were uniform, the better performance of the reference diet could not be attributed to a particular nutritional parameter since there were many variables between the diets. The gross changes investigated with the test diet were an increase in protein, lipid and energy levels and a concomitant decrease in carbohydrate and L:Cho ratios (table 1). These modifications to the reference diet were clearly disadvantageous, particularly in terms of survival and feeding efficiency, probably as a result of the excessive levels of dietary protein (52.6%), lipid (11.2%) and total energy (4.3 $Kcal.g^{-1}$). Previous work in the laboratory has suggested optimum requirements for dietary protein of 40-50%, lipid of 7-9% and carbohydrate of 20-40% for juvenile *P. monodon* (Sedgewick, 1979, Alava and Lim, 1983, Deshimaru *et al.*, 1985; Alava and Pascual, 1987). Optimum dietary energy levels have not been well researched in either the laboratory or the field. Published dietary protein and lipid optima from laboratory-based studies seem to be confirmed for concrete nurseries from the results with these diets. The high levels of dietary energy may have limited the feed intake of the shrimp due to the ingestion of large quantities of energy-rich substrates. The use of higher levels of carbohydrate at lower energy levels in order to spare protein may present a better and cheaper method of enhancing dietary quality. Diets with reduced levels of energy and increased carbohydrate will be tested during future trials in this nursery system.

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