www.trjfas.org
ISSN 1303-2712
Turkish Journal of Fisheries and Aquatic Sciences 14: 487-496 (2014) DOI: 10.4194/1303-2712-v14_2_20

Water Budgeting in Black Tiger Shrimp *Penaeus monodon* Culture Using Different Water and Feed Management Systems

Rajeeb K. Mohanty[1,]*, Atmaram Mishra[2], Dhiraj U. Patil[1]

[1] Directorate of Water Management, Indian Council of Agricultural Research, Bhubaneswar - 751023, Odisha, India.
[2] International Water Management Institute, Southern Africa Centre, Pretoria, South Africa.

* Corresponding Author: Tel.: +94.371 43400; Fax: ;
E-mail: rajeebm@yahoo.com

Received 23 October 2013
Accepted 30 May 2014

Abstract

We quantify the total water use (TWU) and consumptive water use index (CWUI) in grow-out culture of *Penaeus monodon* at different water and feeding management protocols using the water balance equation. Under two different water management protocols, treatment-wise TWU, was 2.09 and 2.43 ha-m 122 d^{-1} in T_1 (no water exchange) and T_2 (water exchange on 'requirement' basis depending on water quality), respectively. The computed CWUI (m^3 kg^{-1} biomass), was 5.35 and 6.02 in T_1 and T_2, respectively. Lower rates of water exchange (T_2) showed significantly improved water quality, crop performance and productivity over the zero water exchange protocol. Similarly, under three different feed management protocols, treatment-wise estimated TWU was 2.52, 2.44 and 2.41 ha-m 119d^{-1}, while the computed CWUI was 7.28, 6.88 and 6.34 in T_1 (Regular feeding, 4-times a day), T_2 (2-weeks feeding followed by 1-week no feed) and T_3 (4-weeks feeding followed by 1-week no feed), respectively. Higher the feed input, higher was the TWU and CWUI. It was also recorded that longer the refeeding period, higher was the growth performance and yield as in the case of T_3. This feeding practice also helped in lowering the feed input (7.5% in T_2 and 5.5% in T_3), thus minimizes the input cost and improve production efficiency.

Keywords: Water budgeting, consumptive water use, *Penaeus monodon*, water quality, growth performance.

Introduction

Aquaculture production has increased more than 40 times since 1970 (63.6 million tonnes), and its economic importance is increasing concomitantly (FAO, 2012). Among various aquaculture production systems, one of the fastest growing sectors is that of the penaeid shrimp. Black tiger shrimp *Penaeus monodon* is one of the most important species of *Penaeus* currently being cultured commercially in many countries. In India, the export oriented shrimp-based coastal aquaculture contributes about 5% shares, accounted for about 60% of shrimp exported from the country (FAO, 2011), is mainly dominated by the giant tiger prawn (*Penaeus monodon*), followed by the Indian white prawn (*Fenneropenaeus indicus*). *P. monodon* culture in India, mainly, receives maximum importance due to its high growth rate, unique taste, high nutritive value and persistent demand in the global market. Although the country possesses huge brackishwater resources of over 1.2 million hectare suitable for shrimp farming; around 157,000 ha have been brought under cultivation (Abraham and Sasmal, 2009) and the average production ranges between 1.5-3.0 t/ha depending upon the stocking density. Shrimp farming plays an important but controversial role in the economic development of many countries in Asia because of the high economic returns and often catastrophic environmental impact of production in coastal areas (Naylor *et al.*, 2000). Most of the nutrients discharged from intensive shrimp farms originate from the formulated feed. Apart from being an unnecessary expense, unconsumed feed contributes to the deterioration of pond water quality when subjected to microbial activity (Focken *et al.*, 1998). Therefore, efforts to improve feeding strategies and water quality must focus on both optimizing production and minimizing waste (Smith *et al.*, 2002; Soundarapandian *et al.*, 2009).

Unplanned wasteful use of water in aquaculture is limiting further development of this sector. As evident, on-farm water use in aquaculture can be very high, attaining values of up to 45 m^3 per kg biomass produced in ponds (Verdegem *et al.*, 2006). Intensification of aquaculture or intensive aquaculture production systems are therefore required to minimize on-farm water use per kg biomass product, to make the system more water-efficient. Keeping this in view, shrimp culture in recent years has evolved from 'open

© Published by Central Fisheries Research Institute (CFRI) Trabzon, Turkey
in cooperation with Japan International Cooperation Agency (JICA), Japan

system' with frequent water discharge to 'closed system' with little or 'zero' water discharge (Arnold *et al*., 2009). However, the major problem associated with closed system is the rapid eutrophication in ponds, resulting from accumulated nutrients and organic matters over the culture period (Thakur and Lin, 2003). Further, in static water pond, evaporation, percolation and seepage represent the largest water loss. To maintain this water loss, pond fertility and survival of stocked animal; replenishment / exchange of water becomes essential. Usually, farmers use to carry out unplanned water exchange that becomes counterproductive and uneconomical. Therefore, quantification of water requirement plays a critical role which depends on various factors i.e., species, stocking density, growth stage, biomass, plankton and nutrient status, water loss, agro-climatic condition etc. Water requirement is a function of soil, climatic condition, species to be stocked, culture method and management practices. Moreover, it is necessary to assess the necessity of replenishment / exchange followed by quantification of water for replenishment, so that question of wasteful use of water does not arise.

As water will be no longer available for inland aquaculture in an unlimited manner (Mohanty *et al.*, 2014), special efforts on input management (mainly feed) along with quantifying/estimating the water requirement of commercially important fish and prawn species will ensure higher water productivity and profitability. Water budgeting and its judicious use is therefore, a primary requisite towards development of protocols for best water management practice (BWMP) in a commercially important grow-out aquaculture. Although, many researchers have worked on water requirements of various agricultural crops, even for the entire growing season (Ali and Talukder, 2008; Molden *et al.,* 2010), only few studies have been reported so far on water requirement of sub-tropical and tropical fish (Boyd,1982; Teichert-coddingten *et al*., 1988; Green and Boyd, 1995; Mohanty *et al.*, 2009). Also, a very little basic work has also been carried out on water budgets based on pond measurements for different type of systems/ponds and in different climatic conditions (Boyd and Gross, 2000; Boyd, 2005; Boyd *et al.*, 2007; Verdegem *et al.*, 2006; Verdegem and Bosma, 2009; Bosma and Verdegem, 2011). In this backdrop, an attempt was made to quantify the total water requirement and consumptive water use along with feeding management for improving water quality and growth performance of black tiger shrimp in grow-out culture under recommended package of practice.

Material and Methods

Experimental Set Up

The present study was carried out at Parikhi of Balasore district (21°28′44″ N, 87°02′15″ E), Odisha, India, during 2010-2011. During the 1st crop cycle, "water exchange pattern" was taken as treatment using dechlorinated water [T_1- No water exchange (Control) × 3 ponds as replications, T_2- water exchange on 'requirement' basis depending on water quality variables (if the daily variation in average water pH>1.0 or if dissolved oxygen (DO) <3.0 ppm or if transparency <10 cm) × 3 ponds as replications]. Water exchange (WE) was decided on the basis of Kg. shrimp m^{-2} × (100 × EF), where EF= exchange factor i.e., 0.1-0.25 for stocking density of 10-35 post-larvae m^{-2} (Mohanty, 2000). Culture duration was 122 days. Pond size was 5000 m^2 each. During the 2nd crop cycle, feeding management was taken as treatment with 3 replications each [T_1: Regular feeding, 4-times a day, T_2: 2-weeks feeding followed by 1-week no feed, T_3- 4-weeks feeding followed by 1-week no feed]. The best water management protocol resulting from the 1st crop cycle was in practice. Culture duration was 119 days. Pond size was 5000 m^2 each.

Pond Preparation, Stocking and Pond Management

Pre-stocking pond preparation for brackish water monoculture of *P. monodon* included horizontal ploughing followed by application of lime ($CaCO_3$) at the rate of 300 kg ha^{-1} followed by longitudinal ploughing and application of lime ($CaCO_3$) at the rate of 200 kg ha^{-1}. After liming, pond was filled with dechlorinated water from the reservoir followed by fertilizer (Urea : Single Super Phosphate; 1:1) application at the rate of 4 ppm. Seven days after pond preparation, stocking operation was carried out. To maintain plankton population in the eco-system, periodic liming and fertilization was carried out. Pond aeration (4-8 hours) mainly in the evening hours, using four 1-hp paddle wheel aerators per pond was a regular practice, after 60 days of culture (DOC). Recommended stocking density of 100,000 Post-Larvae (PL_{22}) of *P. monodon* ha^{-1} were maintained (ICAR, 2005). Stocking was carried out with proper acclimatization procedure. Management practices and inputs were same for all treatments and replications.

Environmental Variables

Recommended minimum water depth (ICAR, 2005) of 1.0 m for monoculture of *P. monodon* was maintained for each treatment. Required depth was maintained on weekly basis either adding or withdrawing water from the experimental ponds. Major physico-chemical parameters of pond water, e.g., Temperature, pH, Dissolved oxygen (DO) and transparency were recorded daily between 0700-0800 hours and during 1500-1600 hours using a Multi-parameter Water Analyzer (YK-611, Yeo-Kal Electronics Pty. Ltd., Australia). Total alkalinity, total suspended solids, dissolved organic matter and CO_2 were monitored *in-situ* every week between 07:^{00}-08:^{00} hours and during 15:^{00}-16:^{00} hours using standard methods (APHA, 1995; Biswas, 1993). Salinity was measured daily using a refractometer (ATAGO S-10, Japan). NH_4^+ was determined spectrophotometically with the indophenol blue method, while chlorophyll-*a* was determined using the acetone extraction method (Strickland and Parsons, 1972). Primary productivity was analyzed using the "Oxygen method" (APHA 1995), while nutrient analysis following standard methods (Biswas, 1993). Plankton samples were collected at fortnightly intervals by filtering 50 L of water from each unit through a silk net (No. 25, mesh size 64 μm), preserved in 4% formaldehyde and later analyzed for quantitative and qualitative estimation.

Sediment Quality

Surface sediment samples up to a depth of 3 cm were collected twice from the pond during each crop period (before stocking and after harvesting) using a spatula and analyzed for pH, available nitrogen (De, 1962), available phosphorus (Troug, 1930) and organic carbon (Walkley and Black, 1934).

Feeding Management

Artificial high-energy supplemental feed (NOVO feed of C.P. Group, Thailand) was used during the experimental periods. The adopted site-specific feeding schedule (Table 1) and feeding management (Mohanty, 2001) was mainly for proper utilization of feed, minimal wastage and better growth of shrimp. Feed adjustment was carried out after observing the meal to meal check tray feeding performance, average body weight and weather condition. Keeping the size of pond and position of aerator in view, four check trays per pond (one check tray approximately for every 1250 m^2) were used (Mohanty, 1999). Feeding frequency of four times a day was adopted throughout the experimental periods. Feed percentage (60.0-2.0), lift net % (2.4-4.2) and time control (2.5 h-1.0 h) to check the check tray feeding performance was followed for mean body weight (MBW) of 0.02-35.0g, respectively. Daily feed requirement, % feed used, amount of check tray feed, and feed increment per day was estimated using formulas as described by Mohanty (1999). Apparent feed conversion ratio (AFCR) and feeding efficiency (FE) was estimated as follows:

AFCR = Total feed used in kg / Net biomass gain in kg (1)

FE = Biomass gain in kg/ feed used in kg × 100 (2)

Growth and Yield Parameters

Weekly growth study was carried out by sampling prior to feeding, so that complete evacuation of gut was ensured. Weekly mean body weight (MBW in g), mean total length (cm), condition factor (Kn), average daily growth or per day increment (PDI in g), absolute growth (g), survival rate (%), and biomass (kg) was estimated using formulas as described by Mohanty (1999). Other growth parameters such as performance index (PI), production-size index (PSI) and specific growth rate (SGR, in % d^{-1}) were estimated as follows:

PI = Per day increment (PDI in g) × Survival rate in % (3)

PSI = Production in kg ha^{-1} × MBW in g / 1000 (4)

SGR = ln final weight - ln initial weight / Days of culture (DOC) ×100 (5)

Table 1. Feeding programme for monoculture of *P .monodon*

Blind Feeding Programme (Initial 30 Days)					
Days of culture	Feed increase/ day/ 100000 PL	Feed/Day/100000 PL		Feed Type	
1	-	1.2 kg		Starter-1	
2-10	200g	1.4-3.0 kg		Starter-1 & 2	
11-20	250g	3.25-5.5 kg		Starter-2	
21-30	300g	5.8-8.5 kg		Starter-2	
Detailed Feeding Programme					
MBW (g)	% Feed	Feed Type	Frequency	%Lift net	Time control
0.02-2.0	60.0-8.0	Starter-1,2	4	2.4-2.5	2.5 h
2.0-6.0	8.0-5.4	Starter-2	4	2.5-2.6	2.5 h
6.0-11.5	5.4-4.3	Grower	4	2.6-2.9	2.0 h
11.5-16.5	4.3-3.8	Grower	4	2.9-3.3	2.0 h
16.5-20.0	3.8-3.4	Grower	4	3.3-3.7	2.0 h
20.0-24.0	3.4-3.0	Grower	4	3.7-3.9	1.5 h
24.0-28.5	3.0-2.4	Finisher	4	3.9-4.0	1.5 h
28.5-35.0	2.4-2.0	Finisher	4	4.0-4.2	1.0 h

N.B.: From 25th day, check trays are immersed in to the ponds with some amount of feed for every meal upto 30th day, so that baby shrimps are made to learn their check tray feeding habit. From 31st day onwards till harvesting, meal to meal feed adjustment is done on the basis of check tray feed consumption. PL: post-larvae.

Water Budgeting

The general hydrological/ water balance equation, inflow = outflow±change in volume (ΔV), can be used to make accurate estimates of water use by ponds for inland aquaculture. Total water use (TWU) is the sum of all possible inflows to aquaculture ponds such as precipitation (P), runoff (R), stream inflow, groundwater seepage (S_i), and management additions or regulated inflows (I) whereas, consumptive water use (CWU) includes the possible outflows such as evaporation (E), seepage (S_o), transpiration, overflow (O_f), intentional discharge or regulated discharge (D), and water in harvest biomass (about 0.75 m^3/t, Boyd *et al.*, 2007) a negligible amount that can be ignored. Commercial aquaculture ponds seldom receive direct inflow from streams. Further, aquatic weeds are prevented from growing in and around edges of ponds, while water is rarely used for activities other than aquaculture. Therefore, stream inflow, and transpiration are seldom major factors. As embankment ponds are small watersheds, and therefore, runoff is negligible and groundwater inflow is also seldom a factor (Boyd and Gross, 2000). Thus the appropriate equation is:

$$P+I = E + S_o + O_f + D \pm \Delta V \qquad (6)$$

Further, the difference between the total and consumptive water use, refers to non-consumptive water use (NWU). A water use index that indicates the amount of water used per unit production in an aquaculture system could be useful. Although this index could be calculated for both total and consumptive water use, the consumptive water use index (CWUI) would be most meaningful (Boyd, 2005). The index could be calculated as shown below:

$$\text{CWUI} = \text{CWU in m}^3 / \text{Production in kg} \qquad (7)$$

To estimate the CWU, a recording water level gauge was installed in each pond to measure the water loss (evaporation + seepage), the inflow and outflow during the experimental period. Further, to separate the evaporation from the total loss, evaporation was estimated using the following equation:

$$\text{Pond evaporation (mm)} = \text{Pond-pan coefficient} \times \text{Class-A pan evaporation (mm)} \qquad (8)$$

Pond pan coefficient of 0.8, most appropriate for ponds, was used in the above equation as suggested by Boyd and Gross (2000). The pond seepage was quantified by subtracting the evaporation loss from the total loss.

Statistical Analysis

Statistical analysis was carried out by using SAS, Version 9 (S.A.S Institute, 2002). Significance ($P<0.05$) of all possible pairs of treatment means was evaluated using the Duncan's multiple range test (Duncan, 1955).

Results and Discussion

Water and Sediment Quality Under Different Water Management Protocols

The continuous monitoring of the physical, chemical and biological parameters of shrimp pond helps not only to predict and control unfavorable conditions for shrimp farming, but also avoids risks of environmental damage and breakage of the production process. The treatment-wise variations in the water and sediment quality parameters in brackish water mono-culture of *P. monodon* under different water management protocols are presented in Table 2. Total suspended solids and the dissolved oxygen concentration show a decreasing trend with the advancement of the rearing period. Higher values of nitrite, nitrate, ammonia and total alkalinity were recorded towards the later part of the experiment. At any given point in time, the remaining water quality parameters and plankton population did not register any specific trend between the treatments. Diatoms and green algae mainly dominated the phytoplankton population while the zooplankton population was dominated by copepods and rotifers. In all the treatments, average primary production in the first month of cultivation ranged from 92.2 to 121 mg C m^{-3} h^{-1}, which improved further (365.2±41.3 mg C m^{-3} h^{-1}) with the advancement of rearing period. Low primary production in the initial phase of rearing was probably due to the fixation of nutrient ions by suspended soil/clay particles as well as rich organic matter (Mohanty, 2003, 2004).

From a shrimp rearing point of view, various hydro-biological parameters prevailing in the different treatments were within the optimum ranges and did not fluctuate drastically. This was probably due to the similar levels of inputs in all the treatments in the forms of inorganic fertilizer and periodic liming. Salinity had a strong influence on various energy parameters, namely energy deposited for growth, energy lost for respiration, energy lost in feces, energy lost in excretion and energy lost in exuviae, but had negligible influence on feeding rate. To date, we know that *P. monodon* has a salinity tolerance range from 1 psu to 57 psu (Chen, 1990) and an optimal salinity range of 10 psu to 35 psu (Liao, 1986), while the iso-osmotic point of *P. monodon* is about 750 mOsm kg^{-1}, equivalent to 25 psu, (Ye *et al.*, 2009). The culture of *P. monodon* in salinities closer to the iso-osmotic point, where osmotic stress will be the lowest, would result in decreased metabolic demands and therefore increased growth. In this study, average salinity however, ranges between 16.6-19.4 psu. The decreasing trend in DO in all the treatments with the advancement of the shrimp rearing period, attributed to the fluctuations in

Table 2. Treatment-wise variations in the water and sediment quality parameters in brackish water monoculture of *P. monodon* under different water management protocols

Parameters	No Water Exchange (T_1)	Regulated Water Exchange (T_2)
Water quality parameters		
Water pH	7.31±0.11	7.63±0.13
Salinity (PSU)	16.6±1.9	19.4±2.2
Dissolved Oxygen (ppm)	4.4±1.1	5.9±1.3
Temperature (°C)	28.4±0.5	28.5±0.3
Transparency (cm)	18±5.2	27±3.8
Total alkalinity (ppm)	104±15	118±8.5
Dissolved Organic Matter (ppm)	3.6±0.3	3.4±0.4
Total Suspended Solids (ppm)	253±10	245±13
NH_4^+ water (ppm)	0.64±0.02	0.68±0.03
Chlorophyll-a (mg m^{-3})	38.7±4.1	43.1±3.2
Total plankton (units L^{-1})	$3.5x10^4±1.2x10^3$	$4.3x10^{4±}1.1x10^3$
Nitrite – N (ppm)	0.03±0.01	0.04±0.01
Nitrate – N (ppm)	0.37±0.07	0.37±0.06
Phosphate – P (ppm)	0.24±0.04	0.21±0.03
Sediment quality parameters		
Available-N in soil (mg 100 g^{-1})	19.9±0.2	19.4±0.3
Available-P in soil (mg 100 g^{-1})	2.22±0.06	2.21±0.08
Organic carbon in soil (%)	0.6±0.01	0.64±0.01
Soil pH	7.02±0.09	7.01±0.08

All values are mean±SD.

plankton density and a gradual increase in biomass, resulting in higher oxygen consumption. Most warm water species require a minimum DO of 1 ppm for survival and 5 ppm for ideal growth and maintenance (Yaro *et al.*, 2005). During the study period, water exchange was carried out three times as daily morning DO fall below 3.0 ppm in T_2. However, in this study the weekly average morning DO level did not drop below 3.3 ppm in any treatments. The stable level of dissolved oxygen in this study could be attributed to proper aeration that raised the dissolved oxygen level to allow aerobic bacteria to reduce biochemical oxygen demand and thus improve water quality.

Gradual increases in nitrite, nitrate, and ammonia were attributed to intermittent fertilization, increased levels of metabolites and decomposition of unutilized feed in the absence of water replenishment (Mohanty, 2000). In general, the poor growth performance of cultured species takes place at pH <6.5, while higher values of total alkalinity (>90 ppm) indicates a more productive eco-system (Mohanty *et al.*, 2009 and Mohanty, 2010b). Enhanced nutrient input affected plankton density and composition. Diatom and Copepoda dominance was replaced by rotifers as nutrient concentrations increased with the cultured period, indicating that plankton structure is affected by eutrophic conditions. Phytoplankton and zooplankton make excellent indicators of environmental conditions and aquatic health within ponds because they are sensitive to changes in water quality. In this experiment, fluctuating trends in plankton density ($3.5x10^4$ to $4.3x10^4$) were recorded in different treatments (Table 2), which ultimately reflected the overall water quality and shrimp yields in the T_1 and T_2 (Table 3). Chlorophyll-a concentration increased with the progress of rearing, indicating that the system never became nutrient limiting, and thus, in turn, sustained high phytoplankton biomass. Seemingly, dissolve nutrients together with the high light intensity, and warm temperature supported active growth of phytoplankton. The availability of CO_2 for phytoplankton growth is linked to total alkalinity (Mohanty, 2003; Mohanty *et al.*, 2010c), while water having 20 ppm to150 ppm total alkalinity produced a suitable amount of CO_2 to permit plankton production. In this study, the recorded minimum and maximum range of total alkalinity was 99 ppm to 126 ppm, which was maintained due to periodic liming. An overall improved water quality was recorded in T_2 (Table 2) followed by T_1, probably due to the regulated water exchange. Regulated or less water exchange also increases the hydraulic retention time (HRT) in ponds. The hydraulic retention time of static ponds usually is weeks or even months, and in ponds with water exchange, HRT usually is a week or more (Boyd *et al.*, 2007).This allows natural processes to assimilate wastes more completely and reduces loads of potential pollutants in effluent (Boyd, 2005).

Soils of the experimental ponds were clay, having an acidic pH (6.6-6.8). The composition of sand, silt and clay was 31.3%, 19.6%, and 49.1 %, respectively. Organic carbon (%), available N and P in soil (mg 100 g^{-1}) varied between 0.17-0.29, 7.7-9.1 and 1.01-1.28, respectively at the beginning of the experiment which was improved later (Table 2). This was likely due to (1) a large fraction of the input nutrients that ends up in the sediment (Acosta-Nassar *et al.*, 1994; Boyd, 1985), (2) shrimp grazing on the photosynthetic aquatic biomass and other components of the system, thereby aiding in nutrient cycling (Mohanty *et al.*, 2009). No distinct trends between the treatments were observed and the sediment characteristics of the different treatments were indicative of a medium productive soil group (Banerjee, 1967).

Water and Sediment Quality Under Different Feeding Management Protocols

Similarly the treatment-wise variations in the water and sediment quality parameters in brackish water mono-culture of *P. monodon* under different feed management protocols are presented in Table 4. Higher values of dissolved organic matter, total suspended solids, chlorophyll-a, nitrite, nitrate, ammonia and total alkalinity were recorded towards the later part of the experiment. At any given point in time, except the total alkalinity and total suspended solids, the remaining water quality parameters and plankton population did not register any specific trend between the treatments. Significantly better water quality parameters ($P<0.05$) were recorded in T_2 (Table 4) where frequency of feed restriction was higher (less feed input) followed by T_3 and T_1. The feeding strategy used in the commercial culture of shrimp has a significant impact on pond water quality and hence growth, health and survival of the shrimp, as well as the efficiency of feed utilization (Table 5). Excess feeding can result in an increase in organic material and a decrease in DO as in T_1 followed by T_3, due to oxidation by bacteria and an increase in metabolic wastes (Allan *et al.*, 1995). Soils of the experimental ponds were clay, having an acidic pH (6.7-6.9). The composition of sand, silt and clay was 31.1%, 19.9%, and 49.0 %, respectively. Organic carbon (%), available N and P in soil (mg 100 g^{-1}) varied between 0.19-0.28, 7.7-9.6 and 1.05-1.23, respectively at the beginning of the experiment which was improved later (Table 4). No distinct trends between the treatments were observed and the sediment characteristics were indicative of a medium productive soil group.

Water Budgeting Under Different Water and Feed Management Protocols

Water budgeting under different water

Table 3. Growth and production performance of *P. monodon* under different water management protocols

Parameters	No water exchange (T_1)	Regulated water exchange (T_2)
Mean Body weight, MBW (g)	28.56±0.25	30.4±0.40
Per Day Increment, PDI (g)	0.23±0.00	0.25±0.00
SGR (% d^{-1})	5.95±0.00	6.00±0.01
Survival Rate, (SR%)	74.56±3.58	80.13±1.70
Productivity (t ha^{-1})	2.13±0.11	2.44±0.081
Performance Index, PI	17.15±0.82	19.75±0.75
Production-Size Index, PSI	60.88±3.52	74.1±3.40
Apparent Feed Conversion Ratio, AFCR	1.43±0.05	1.42±0.01
Feed Efficiency, FE (%)	69.95±2.66	70.2±0.74

All values are mean±SD. Initial MBW= 0.02g. Days of culture=122d.

Table 4. Treatment-wise variations in the water and sediment quality parameters under varied feeding protocols in brackish water monoculture of *P. monodon*

Parameters	T_1	T_2	T_3
Water quality parameters			
Water pH	$7.22±0.11^{b}$	$7.54±0.13^{a}$	$7.41±0.17^{ab}$
Dissolved Oxygen (ppm)	$4.9±1.2^{b}$	$6.1±0.7^{a}$	$5.2±1.1^{b}$
Salinity (PSU)	$17.4±2.1^{b}$	$19.1±1.8^{a}$	$17.6±1.9^{b}$
Temperature (°C)	$28.7±0.6^{a}$	$28.5±0.3^{a}$	$28.6±0.5^{a}$
Total alkalinity (ppm)	$96±8^{c}$	$118±7^{a}$	$106±10^{b}$
Dissolved Organic Matter (ppm)	$4.9±0.2^{a}$	$3.7±0.4^{b}$	$3.8±0.3^{b}$
Total Suspended Solids (ppm)	$241±13^{a}$	$192±13^{c}$	$224±11^{b}$
NH_4^+ water (ppm)	$0.61±0.03^{b}$	$0.7±0.03^{a}$	$0.67±0.02^{ab}$
Chlorophyll-a (mg m^{-3})	$44.3±5.3^{a}$	$37.7±4.2^{b}$	$43.1±3.2^{a}$
Total plankton (units L^{-1})	$4.6x10^4±1.4x10^{3a}$	$3.8x10^4±1.1x10^{3b}$	$3.6x10^4±1.3x10^{3\,b}$
Nitrite – N (ppm)	$0.04±0.00^{a}$	$0.04±0.01^{a}$	$0.03±0.01^{a}$
Nitrate – N(ppm)	$0.37±0.07^{a}$	$0.37±0.06^{a}$	$0.36±0.09^{a}$
Phosphate – P (ppm)	$0.25±0.04^{a}$	$0.21±0.03^{b}$	$0.2±0.04^{b}$
Sediment quality parameters			
Available-N in soil (mg 100 g^{-1})	$22.6±0.2^{a}$	$21.1±0.3^{c}$	$21.8±0.2^{b}$
Available-P in soil (mg 100 g^{-1})	$2.21±0.06^{a}$	$2.23±0.07^{a}$	$2.11±0.07^{b}$
Organic carbon in soil (%)	$0.65±0.01^{a}$	$0.66±0.01^{a}$	$0.62±0.01^{b}$
Soil pH	$6.97±0.07^{a}$	$7.01±0.08^{a}$	$7.04±0.09^{a}$

All values are mean±SD. Values with different superscripts in a row differ significantly ($P<0.05$).

management protocols was carried out (Table 6) to estimate the consumptive and non-consumptive water use. Under brackishwater monoculture of *P. monodon*, treatment-wise estimated TWU (culture duration-122d) was 2.09 and 2.43 ha-m in T_1 and T_2, respectively, while the computed CWUI (m^3 kg^{-1} biomass) was 5.35 and 6.02 in T_1 and T_2, respectively. This result is in agreement with the findings of Anh *et al.* (2010), who reported water use of 6.65 m^3/kg biomass in black tiger shrimp farming. Evaporation and seepage losses contribute significantly to CWU (Table 6). Average seepage loss was 4.4 mm d^{-1}, while the average evaporation loss was 4.92 mm d^{-1}. Evaporation loss is a function of climatic condition and culture duration. On an average, 5.2 m^3 water per kg production is consumed through evaporation from ponds (Bosma and Verdegem, 2011). However in the present study, evaporation loss was 2.4-2.8 m^3 water kg^{-1} production in brackishwater monoculture of *P. monodon*. Water use in ponds usually varies with the intensity of production, frequency and amount of water exchange employed. Higher the amount of water exchange, higher is the TWU as in case of T_2. Shrimp production typically requires TWU between 20-40m^3/kg shrimp in intensive brackish water culture, where daily water exchange is a regular practice (Boyd, 2005; Boyd *et al.*, 2007). Presently, on-farm water use in aquaculture can be as low as 0.5–0.7 m^3 in super-intensive re-circulation systems and as high as 45 m^3 of water per kilogram of produce in extensive pond system (Verdegem *et al.*, 2006). In general, total water use varies greatly in aquaculture depending mainly upon the culture method used. Therefore, among different culture practices, cage and net pen culture use the least water, and raceway culture uses the most.

Similarly, water budgeting under different feed management protocols was carried out (Table 6) to estimate the consumptive and non-consumptive water use. Under brackishwater monoculture of *P. monodon*, treatment-wise estimated TWU (culture duration-119d) was 2.52, 2.44 and 2.41 ha-m in T_1, T_2 and T_3, respectively, while the computed CWUI (m^3 kg^{-1} biomass) was 7.28, 6.88 and 6.34 in T_1, T_2 and T_3, respectively (Table 6). Higher the feed input, higher was the water exchange requirement, TWU and CWUI. Evaporation (5.06 mm d^{-1}) and seepage losses (4.4 mm d^{-1}) contribute significantly to CWU (Table 6). In the present study, evaporation loss range between 2.6-2.8 m^3 water kg^{-1} productions in

Table 5. Growth and production performance of *P. monodon* under different feeding management protocols

Parameters	T_1	T_2	T_3
Mean Body weight, MBW (g)	27.56±0.25^b	27.43±0.37^b	29.1±0.17^a
Per Day Increment, PDI (g)	0.23±0^a	0.23±0^a	0.24±0^a
SGR (% d^{-1})	6.07±0.005^b	6.07±0.011^b	6.12±0.005^a
Survival Rate, (SR%)	78.76±4.36^a	79.5±2.94^a	79.13±3.1^a
Productivity (t ha^{-1})	2.17±0.13^a	2.18±0.085^a	2.30±0.078^a
Performance Index, PI	18.11±1.00^a	18.29±0.68^a	18.99±0.74^a
Production-Size Index, PSI	59.86±3.95^a	59.83±2.74^a	66.96±1.97^a
Apparent Feed Conversion Ratio, AFCR	1.47±0.04^a	1.36±0.02^b (7.5%)	1.39±0.02^b (5.5%)
Feed Efficiency, FE (%)	67.7±1.86^b	73.5±1.41^a	71.56±1.44^a

All values are mean ± SD. Values with different superscripts in a row differ significantly (P<0.05).
Initial MBW= 0.02g. Figures in parenthesis indicate percentage saves in total feed. Days of culture=119d.

Table 6. Water budgeting under different water and feed management protocols

	Monoculture of P. monodon under different water management protocol (Days of culture: 122 d)**		Monoculture of P. monodon under different feed management protocol (Days of culture: 119 d)***		
	(T_1)	(T_2)	(T_1)	(T_2)	(T_3)
Evaporation losses, ha-m	0.60	0.60	0.60	0.60	0.60
Seepage losses, ha-m	0.53	0.53	0.52	0.52	0.52
Regulated outflow, ha-m	--	0.32	0.44	0.35	0.30
Other losses, ha-m*	0.01	0.02	0.02	0.03	0.04
Total loss (CWU), ha-m	1.14	1.47	1.58	1.50	1.46
Initial water level, ha-m	0.95	0.96	0.94	0.94	0.95
Precipitation, ha-m	0.51	0.51	0.47	0.47	0.47
Regulated inflow, ha-m	0.63	0.96	1.11	1.03	0.99
TWU, ha-m	2.09	2.43	2.52	2.44	2.41
CWUI in m^3 kg^{-1} biomass	5.35	6.02	7.28	6.88	6.34

* Other loss mainly includes loss through biomass and other ignored losses. CWU: consumptive water use, TWU: total water use, NWU: non- consumptive water use (TWU-CWU), CWUI: consumptive water use index.
**Average seepage loss, evaporation loss and precipitation were 4.4 mm d^{-1}, 4.92mm d^{-1} and 509mm $122d^{-1}$ respectively.
*** Average seepage loss, evaporation loss and precipitation were 4.4 mm d^{-1}, 5.06mm d^{-1} and 472mm $1119d^{-1}$ respectively.

brackishwater monoculture of *P. monodon*. After harvesting, the nutrient rich left-over water (non-consumptive water use, NWU) from the brackish water aquaculture ponds (0.95 ha-m) can be recycled using the bio-pond system (Mohanty and Mohanty, 2001).

Growth and Production Performance of *P.monodon* under Different Water Management Protocols

Water exchange is not necessary in most types of pond aquaculture (Boyd and Tucker, 1998) and has no influence on the overall crop performance (Good *et al.*, 2009). However, controlled water exchange helps in reducing organic and nutrient load, toxic metabolites, reduces turbidity, induces moulting and promotes growth (Mohanty, 2000). In this experiment, the lower rates of water exchange (T_2) showed improved water quality (Table 2), and overall crop performance (Table 3) in terms of PI (19.75±0.75), PSI (74.1±3.4), and productivity (2.44±0.08) over the zero water exchange. Mohanty (2000) reported that that excess water exchange (daily/weekly) has no significant effect on growth and survival of *P. monodon*, except in maintaining a cleaner aquatic environment. In fact, brackish water ponds are highly efficient in assimilating carbon, nitrogen and phosphorus inputs. If water exchange is unnecessarily more, these substances will be discharged from the pond ecosystem before they can be assimilated (Mohanty, 2000 and Boyd, 2005). Higher MBW and survival rate in T_2 were probably due to the minimal water exchange and the prevailing optimal salinity (19.4±2.2 ppt), DO (5.9±1.3 ppm) and water pH (7.63±0.13). The optimal range of salinity (15-25 ppt) and water pH (7.5-8.5) plays a key role in growth, survival and yield of *P.monodon* (Anh *et al.*, 2010). As the oxygen budget is strongly influenced by the balance/ dominance of autotrophic/ heterotrophic process, lower dissolved oxygen concentration might be attributed to the decreased autotrophic/increased heterotrophic activity (Mohanty *et al.*, 2009). This probably affected the survival and productivity in T_1, in absence of water exchange. Although overall yield and survival were higher in T_2, water exchange had no effect on SGR, feed efficiency and AFCR (Table 3). The low AFCR value obtained in this study may be ascribed to the strict control of feeding by trays.

Growth and Production Performance of *P.monodon* under Different Feeding Management Protocols

P. monodon is a continuous-intermittent feeder. This feeding behavior dictates the feed management strategy. Among different feed management protocols, overall crop performance was similar in both T_1 and T_2 (Table 5). However, significantly ($P<0.05$) low AFCR and higher FE in T_2 over T_1, was probably due to the prevailing optimal salinity (19.1±1.8 ppt), DO (6.1±0.7 ppm) and water pH (7.54±0.13). The optimal range of salinity (15-25 ppt) and water pH (7.5-8.5) plays a key role in growth, survival and yield of *P. monodon* (Anh *et al.*, 2010). The low AFCR value obtained in this study may be ascribed to the strict control of feeding by trays and site specific feeding schedule (Table 1). Among T_2 and T_3, there was no significant ($P<0.05$) variation in overall crop performance except in SGR and MBW (Table 5). This was probably due to the longer refeeding periods after cyclic food deprivation that successfully triggered compensatory growth response (Mohanty 2010a). It was also recorded that longer the refeeding period, higher was the growth performance (MBW, PDI, SGR, PI and PSI) and yield (Table 5) as in the case of T_3. However, cyclic food deprivation and refeeding (T_2 and T_3) showed no significant impact on the survival rate, but significantly enhanced ($P<0.05$) the feed conversion efficiency of the cultured species as well as the apparent feed conversion ratio. Usually, specific growth rate (SGR), which assumes exponential growth over the examined growth interval, is often used to estimate the rate of weight increase. If the fish from feed restricted (manipulated) groups have a higher SGR than the control group, they are said to exhibit full compensatory growth (Mohanty, 2010a) as in the case of T_3. Cyclic food deprivation and refeeding also helped in maintaining water quality due to the restricted feed input (7.5% in T_2 and 5.5% in T_3), thus minimizes the input cost and improves production efficiency (Oh *et al.*, 2008; Turano *et al.*, 2008). Significantly better water quality parameters ($P<0.05$) were recorded in T_2 (Table 4) where frequency of feed restriction was higher (less feed input) followed by T_3 and T_1. Apart from being an unnecessary expense, unconsumed feed contributes to the deterioration of pond water quality when subjected to microbial activity. The results in the present study also indicate that *P. monodon* have the ability to with stand and recover from periodic starvation after cyclic feeding periods. This agrees with the findings of Zhang *et al.* (2009), in case of the Chinese shrimp *F. chinensis*.

Conclusions

The aquaculture industry is under increasing pressure to make production more resource efficient and environmentally responsible. Application of better management practices is the main approach for improving the environmental performance of aquaculture. The potential to increase aquaculture production by expanding the present pond area and raising water consumption is limited. Consequently, the most sustainable way to increase aquaculture production is through intensification of existing aquaculture systems with emphasis on water cutback approach. Minimization of total water use (2.41- 2.52 ha-m) and taking advantage of the compensatory growth response, also perceived as a way to improve water quality due to the restricted feed input (about 7.5%), increase productivity and profits in aquaculture operations. Water budgeting for different species and target of productions may form the practical tools for generating useful information for mitigating the challenges on water for aquatic production.

Acknowledgements

The authors are thankful to the Director, Directorate of Water Management, Bhubaneswar, Odisha, India for providing all the facilities during the research work. Comments of the anonymous reviewers certainly improved the quality of this manuscript.

References

Abraham, T. J. and Sasmal, D. 2009. Influence of salinity and management practices on the shrimp (*Penaeus monodon*) production and bacterial counts of modified extensive brackishwater ponds. Turkish Journal of Fisheries and Aquatic Sciences, 9: 91-98.

Acosta-Nassar, M.V., Morell, J.M. and Corredor, J.E. 1994. The nitrogen budget of a tropical semi-intensive freshwater fish culture pond. Journal of the World Aquaculture Society, 25: 261–270. doi: 10.1111/j.1749-7345.1994.tb00189.x

Ali, M.H. and Talukder, M.S.U. 2008. Increasing water productivity in crop production- A synthesis. Agricultural Water Management, 95: 1201–1213. doi:10.1016/j.agwat.2008.06.008

Allan, G.L., Moriarty, D.J.W. and Maguire, G.B. 1995. Effects of pond preparation and feeding rate on production of *Penaeus monodon* Fabricius, water quality, bacteria and benthos in model farming ponds. Aquaculture, 130: 329-349. SSDI OO44-8486 (94)00316-5

Anh, P.T., Kroeze, C., Bush, S.R. and Mol, A.P.J. 2010. Water pollution by intensive brackish shrimp farming in south-east Vietnam: Causes and options for control. Agricultural Water Management, 97: 872–882. doi:10.1016/j.agwat.2010.01.018

APHA 1995. Standard methods for examination of water and waste water. 19th Edn. American Public Health Association. Washington DC., USA, 874 pp.

Arnold, S.J., Coman, F.E., Jackson, C.J. and Groves, S.A. 2009. High-intensity, zero water-exchange production of juvenile tiger shrimp, *Penaeus monodon*: An evaluation of artificial substrates and stocking density. Aquaculture, 293: 42–48. doi:10.1016/j.aquaculture.2009.03.049

Banerjee, S.M. 1967. Water quality and soil condition of fishponds in some states of India in relation to fish production. Indian J. Fish., 14: 115-144.

Biswas, K.P. 1993. Fisheries manual. Bhagabat press and publishers, Cuttack, Orissa, India.

Bosma, R.H. and Verdegem, M.C.J. 2011. Sustanable aquaculture in ponds: Principles, practices and limits. Livestock Science, 139: 58-68. doi:10.1016/j.livsci.2011.03.017

Boyd, C.E. 1982. Hydrology of small experimental fishponds at Auburn, Alabama. Trans. Am. Fish. Soc., 111: 638-44. doi:10.1577/1548-8659(1982)111

Boyd, C.E. 2005. Water use in aquaculture. World Aquacult., 36(3): 12–15 and 70

Boyd, C.E. and Tucker, C.S. 1998. Pond Aquaculture Water Quality Management. Kluwer Academic Publishers, Boston, MA, 700 pp.

Boyd, C.E. and A., Gross. 2000. Water use and conservation for inland aquaculture ponds. Fisheries Management and Ecology, 6:1-9.

Boyd, C.E., Tucker, C.S., Mcnevin, A., Bostick, K. and Clay, J. 2007. Indicators of Resource Use Efficiency and Environmental Performance in Fish and Crustacean Aquaculture. Reviews in Fisheries Science, 15: 327–360, doi: 10.1080/10641260701624177

Boyd, C.E. 1985. Chemical budgets for channel catfish ponds. Transactions of the American Fisheries Society, 114, 291–298. doi:10.1577/1548-8659(1985)

Chen, L.C. 1990. Aquaculture in Taiwan. Oxford. Fishing News Books, London, UK, 278 pp.

De, S.K. 1962. Methods of soil analysis. Narayan Publishing House, Allahabad, India, 204 pp.

Duncan, D.B. 1955. Multiple range and multiple f-test. Biometrics, 11: 1-42.

FAO 2011. Fishery and Aquaculture Country Profiles: India (available at www.fao.org).

FAO 2012. The State of World Fisheries and Aquaculture 2012. FAO Fisheries and Aquaculture Department, Rome, 209 pp.

Focken, U., Groth, A., Coloso, R.M. and Becker, K. 1998. Contribution of natural food and supplemental feed to the gut content of *Penaeus monodon* Fabricius in a semi-intensive pond system in the Philippines. Aquaculture, 164:105–116. PII: S0044-8486(98) 00180-X

Good, C., Davidson, J., Welsh, C., Brazil, B., Snekvik, K. and Summerfelt, S. 2009. The impact of water exchange rate on the health and performance of rainbow trout *Oncorhynchus mykiss* in water recirculation aquaculture systems. Aquaculture, 294: 80–85. doi:10.1016/j.aquaculture.2009.05.014

Green, B.W. and Boyd, C.E. 1995. Water budgets for fish ponds in the dry tropics. Aquacultural Engineering, 14(4): 347-356. doi:10.1016/0144-8609(95)00002-V

ICAR 2005. Aquaculture technologies for farmers. Indian Council of Agricultural Research. New Delhi, India, 104 pp.

Liao, I.C. 1986. General introduction to the prawn pond system in Taiwan. Aquaculture Engineering, 5: 219–233. doi: 10.1016/0144-8609(86)90018-X

Mohanty, R. K. 1999. Growth performance of *Penaeus monodon* at different stocking densities. J. Inland Fish. Soc. India, 31(1): 53-59.

Mohanty, R.K. 2003. Feed intake pattern and growth performance of Indian major carps and freshwater prawn in a rice-fish integration system. J. Asian Fisheries Sci., 16: 307-316.

Mohanty, R.K. 2004. Density-dependant growth performance of Indian major carps in rainwater reservoirs. J. Appl. Ichthyol., 20(2): 123-127. doi: 10.1046/j.1439-0426.2003.00532.x

Mohanty, R. K. 2010a. Dynamics of the Compensatory Growth Response in Fish. Fishing chimes, 30 (1):78-80.

Mohanty, R.K. 2010b. Impact of phased harvesting on population structure, feed intake pattern and growth performance of *Macrobrachium rosenbergii* DeMan (giant freshwater prawn) in polyculture with carps in concurrent rice–fish culture. Aquaculture International, 18: 523-537. doi 10.1007/s10499-009-9263-5

Mohanty, R.K., Jena, S.K., Thakur, A.K. and Patil, D.U. 2009. Impact of high-density stocking and selective harvesting on yield and water productivity of deepwater rice-fish systems. Agricultural Water Management, 96(12): 1844-1850, doi:10.1016/j.agwat.2009.08.006

Mohanty, R.K. and Mohanty, S.K. 2001. Effluent treatment using bio-pond system in semi-intensive shrimp farm. J. Inland Fish. Soc. India, 33(1): 65-70.

Mohanty, R.K., Thakur, A.K., Ghosh, S., Mohanty, S. and Patil, D.U. 2010c. Performance evaluation of concurrent rice-fish-prawn culture with and without cull harvesting. Aquaculture Research, 41: 1402-1412. doi:10.1111/j.1365-2109.2009.02432.x

Mohanty, R.K. 2000. Performance evaluation of different water exchange pattern on growth and survival of *Penaeus monodon* (Fabricius). J. Aqua., 8: 67-71.

Mohanty, R.K. 2001. Feeding management and waste production in semi-intensive farming of *penaeus monodon* (fab.) at different stocking densities. Aquaculture International, 9: 345–355.

Mohanty, R.K., Kumar, A., Mishra, A., Panda, D.K. and Patil, D. 2014. Water budgeting and management: enhancing aquacultural water productivity. Research Bulletin No: 63, Directorate of Water Management (ICAR), Odisha, India, 62 pp.

Molden, D., Oweis, T., Steduto, P., Bindraban, P., Hanjra, M.A. and Kijne, J. 2010. Improving agricultural water productivity: Between optimism and caution. Agricultural Water Management, 97: 528–535, doi:10.1016/j.agwat.2009.03.023

Naylor, R.L., Goldburg, R.J., Primavera, J.H., Kautsky, N., Beveridge, M.C.M., Clay, J., Folks, C., Lubchenco, J., Mooney, H. and Troell, M. 2000. Effect of aquaculture on world fish supplies. Nature, 405: 1017–1024. doi:10.1038/35016500

Oh, S-Y., Noh, C.H., Kang, R-S., Kim, C-K., Cho, S.H. and Jo, J-Y. 2008. Compensatory growth and body composition of juvenile black rockfish *Sebastes schlegeli* following feed deprivation. Fish. Sci., 74:846–852. doi: 10.1111/j.1444-2906.2008.01598.x

S.A.S. Institute, 2002. SAS Procedures Guide, Version 9. SAS Institute Inc., Cary, NC, USA.

Smith, D.M., Burford, M.A., Tabrett, S.J., Irvin, S.J. and Ward, L. 2002. The effect of feeding frequency on water quality and growth of the black tiger shrimp (*Penaeus monodon*). Aquaculture, 207: 125- 136. *PII*: S0044-8486(01)00757-8

Soundarapandian, P., Sankthivel, K. and Dinakaran, G.K. 2009. Culture of *Penaeus monodon* (Fabricius) by using Cyclop-Eeze Feed. Current Research Journal of Biological Sciences, 1(3): 113-117.

Strickland, J.D.H. and Parsons, T.R. 1972. A Practical Handbook of Seawater Analysis. Fish. Res. Board, Canada.

Teichert-Coddington, D.R., Stone, N. and Phelps, R.P. 1988. Hydrology of fish culture ponds in Gualaca, Panama. Aquacultural Engineering, 7: 309-320. doi:10.1016/0144-8609(88)90013-1

Thakur, D.P. and Lin, C.K. 2003. Water quality and nutrient budget in closed shrimp (*Penaeus monodon*) culture systems. Aquacultural Engineering, 27: 159-176, *PII*: S0144-8609(02)00055-9

Troug, E. 1930. The determination of readily available phosphorus of soils. Journal of American Society of Agronomy, 23: 874-882.

Turano, M.J., Borski, R.J. and Daniels, H.V. 2008. Effects of cyclic feeding on compensatory growth of hybrid striped bass (*Morone chrysops* X *M. saxitilis*) food fish and water quality in production ponds. Aquacult. Res., 39: 1514–1523. doi:10.1111/j.1365-2109.2008.02023.x

Verdegem, M.C.J. and Bosma, R.H. 2009. Water withdrawal for brackish and inland aquaculture, and options to produce more fish in ponds with present water use. Water Policy 11(1): 52-68. doi: 10.2166/wp.2009.003

Verdegem, M.C.J., Bosma, R.H. and Verreth, J.A.J. 2006. Reducing water use for animal production through aquaculture. Water Resources Development, 22(1): 101-113. doi: 10.1080/ 07900620500405544

Walkley, A. and Black, I.A. 1934. An examination of the degtjareff method for determination of soil organic matter and a proposed modification of the cromic acid titration method. Soil Science**,** 34: 29-38.

Yaro, I., Lamani, S.L. and Oladimeji, A.A. 2005. Effect of different fertilizer treatments on water quality parameters in rice-cum-fish culture system. J. Appl. Ichthyol, 21: 399-405. doi: 10.1111/j.1439-0426.2005.00654.x

Ye, L., Jiang, S., Zhu, X., Yang, Q., Wen, W. and Wu, K. 2009. Effects of salinity on growth and energy budget of juvenile *Penaeus monodon*. Aquaculture, 290: 140–144. doi:10.1016/j.aquaculture.2009.01.028

Zhang, P., Zhang, X., Li J. and Gao, T. 2009. Starvation resistance and metabolic response to food deprivation and recovery feeding in *Fenneropenaeus chinensis* juveniles. Aquacult Int., 17: 159–172. doi: 10.1007/s10499-008-9188-4