

# Evaluation of respiration rates and mechanical aeration requirements in semi-intensive shrimp *Litopenaeus vannamei* culture ponds

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Received 11 July 2006; accepted 26 July 2006

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## Abstract

To increase the efficiency of dissolved oxygen management in semi-intensive shrimp *Litopenaeus vannamei* culture in Santa Catarina, Southern Brazil, the present study aimed at characterizing the respiration rates in three ponds (1.2 ha) and estimating the approximate calculation of the actual aeration requirements ( $\text{HP ha}^{-1}$ ) during 9 weeks of a production cycle (February–April, 2003). The sediment respiration rate (SR) and the water column respiration rate (WR) were characterized using the column method, by which ponds initial and final dissolved oxygen concentrations (surface and bottom) were determined, then incubated for 24 h in PVC tubes fixed in the experimental units. SR was significantly higher than WR, except for the third week of culture. SR showed a wide variation ( $0.07\text{--}0.16 \text{ g m}^{-2} \text{ h}^{-1}$ ) during the experiment and the highest respiration rate occurred in the last week of culture. Sediment analyses were done in the beginning and in the end of the experiment, and they also showed differences in the concentration of organic matter (3.4 and 6.3%). On the other hand, WR varied little ( $0.04\text{--}0.07 \text{ g m}^{-2} \text{ h}^{-1}$ ) and presented a pattern similar to photosynthesis, determined by the dark and clear bottles method. Temporal aeration requirements were characterized from SR and WR data, and also from the shrimp mean respiration rate described in the literature. More aeration was required in the last week of culture ( $2.62 \pm 0.06 \text{ HP ha}^{-1}$ ). However, only the aeration calculated for the first week was close to that used in the Yakult Experiment Farm (UFSC), where the study was carried out ( $1.08$  and  $1.70 \text{ HP ha}^{-1}$ , respectively). All aeration estimates from this study were below those used in cultures at UFSC, especially after the third week of experiment.

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**Keywords:** Respiration rate; Aeration; Semi-intensive culture; *Litopenaeus vannamei*

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## 1. Introduction

Paddle-wheel aerators are considered to be the most efficient equipment used in aquaculture (Boyd and Tucker, 1979; Engle and Hatch, 1988; Boyd, 1990). However, although this type of aerator has high oxygen transfer rate per hour, maintenance and operation costs account for as much as 20% of the final price of one kilo

of shrimp. Thus, operation of this tool demands correct calculations to optimize it according to the type of management used and to the characteristics of the region of culture. Adequate use of these aerators requires information on their efficiency in oxygen transfer rate and also the total oxygen consumed in the farming system, which is composed by sediment respiration rate (SR), water respiration rate (WR), and farmed organisms respiration (Fast and Boyd, 1992).

Oxygen budget in channel catfish (*Ictalurus punctatus*) ponds has been extensively studied in the

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literature. In such ponds, most of the oxygen is produced by phytoplankton photosynthesis (76.9%), and it is consumed by their own respiration (57.5%). A smaller portion of the dissolved oxygen (DO) is demanded by fish (22.5%) and sediment (19.4%) respirations. In shrimp ponds these variables are not very well known yet, but it is known that both phytoplankton and water change are dominant factors in oxygen budget, and in some ponds sediment respiration can also be very significant (Boyd, 2001).

Total oxygen demand in tropical aquaculture ponds is of great importance as they are relatively small, shallow, usually with still water and with high input of organic matter (Braathem, 1983). Concentration of organic matter in aquaculture pond sediments often tends to increase with pond aging and it is much higher than the organic matter in the water column (Munsiri et al., 1996; Avnimelech and Ritvo, 2003). Organic matter is constituted by a number of materials such as, feces, uneaten feed, organic manure, dead phytoplankton and zooplankton in different decomposing stages, which demand high amounts of oxygen for total decomposition (Fast and Boyd, 1992; Peterson and Muir, 1999).

Many researches have shown that all the oxygen transferred across on the water surface is to meet the SR demands (Bowman and Delfino, 1980; Davis and Lathrop-Davis, 1986; Porcella et al., 1986; Madenjian, 1990; Berthelson et al., 1996; Avnimelech and Ritvo, 2003; Steeby et al., 2004a,b). In shrimp ponds, SR can constitute more than 50% of the oxygen demand of the entire pond (Madenjian et al., 1987). These values can get so high that oxygen demand of the farmed shrimp may become insignificant (Sharp, 1976; Madenjian et al., 1987).

In this way, more attention should be paid to the pond bottom, because characteristics of the sediment and the processes happening in it and in the water-sediment interface will influence the health and growth of farmed animals. This attention must be doubled in shrimp culture ponds for they live on the water-sediment transition area, feed on precipitated matter, and some species tend to bury in the sediment (Boddeke, 1983; Avnimelech and Ritvo, 2003).

Although several researches are done to improve sediment quality, studies on total oxygen demand in shrimp ponds and aeration requirement during shrimp farming are scarce. Practical and low cost methods allow farmers to monitor pond environmental conditions and also contribute to a better operation of mechanical aeration systems. Therefore, to optimize the use of this technology and to reduce production costs, the present study aimed at characterizing the respiration

rates of the sediment and of the water column, and at estimating the actual mechanical aeration requirements in semi-intensive shrimp *Litopenaeus vannamei* ponds in Southern Brazil.

## 2. Materials and methods

### 2.1. Experiment site and culture management

This study was carried out at Yakult Experiment Farm, of Universidade Federal de Santa Catarina (UFSC), located in Barra do Sul, Santa Catarina state, Brazil (26°32'S and 48°39'W). Three 1.2-ha ponds were used for the experiment and observations were done weekly throughout a complete production cycle (February–April 2003), corresponding to summer and beginning of autumn.

As for pond management, daily water change rate was of 5%, up to three 2-HP paddle-wheel aerators were operated between dusk and dawn (8 h in sunny days and up to 14 h in cloudy days). Stocking density was 21 shrimps m<sup>-2</sup> (*L. vannamei*) with mean initial and final weights of 2.5 and 12 g, respectively. Daily feeding ratio was 6% of the shrimp biomass in the beginning and decreased to 3% by the end of culture. Feeding in trays was done three times a day, following feeding tables (based on pond biomass) and also according to the daily feed intake (35% crude protein).

To assess the variation of physicochemical parameters during the production cycles daily measurements of temperature, pH, salinity, water transparency (at 14:00 h), temperature, and dissolved oxygen (DO) concentration (06:30, 16:00, 24:00 h) were done. All analyses were done at pond water outlet, and the two last parameters were measured on the water surface and in the pond bottom.

### 2.2. Characterization of sediment respiration and water respiration

Sediment respiration rate (SR) and water column respiration rate (WR) were determined through the column method, originally described by Shapiro and Zur (1981) and adapted to aquaculture ponds by Boyd (1995).

In this study, PVC tubes (5 cm diameter, 140 cm height) and a polarographic oxygen meter (YSI 550-A) were used. Three pairs of tubes were placed in each pond, and each pair was fixed at the initial, medium and final lateral margins of the pond, homogeneously representing the studied area (Fig. 1).

Each pair of columns was inserted vertically 10 cm deep in the sediment and leaving 10 cm above the water

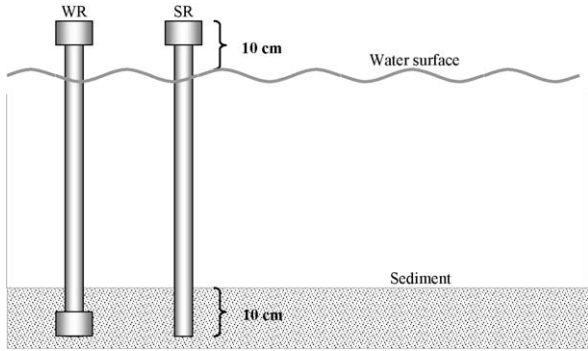


Fig. 1. Schematic drawing of the PVC columns used to determine water respiration rate (WR) and sediment respiration rate (SR).

surface (Fig. 2). Then, they were filled with pond water up to 100 cm height. But previously, the water was filtered through a 100  $\mu\text{m}$  mesh net to remove suspended solids and it was also thoroughly agitated for several minutes to saturate with oxygen.

Following determination of initial DO concentration on the surface and in the bottom for both columns, they were incubated for 24 h to obtain the final DO concentration. With the change in DO concentration due to respiration, SR and WR were determined using the following equation:

$$R = \frac{\Delta\text{DO} H}{T} \quad (1)$$

where  $R$  is respiration ( $\text{g m}^{-2} \text{h}^{-1}$ ),  $\Delta\text{DO}$  the variation in DO due to respiration ( $\text{g m}^{-3}$ );  $H$  the height of the tube with pond water (m), and  $T$  is the time of incubation (h). To avoid photosynthesis inside the columns, any penetration of light was eliminated by painting the tubes dark and capping them with aluminum foil.

Sediment analyses were done in the beginning and in the end of the shrimp culture to have a better understanding of SR and of the importance of increased organic matter in oxygen depletion. For each experiment

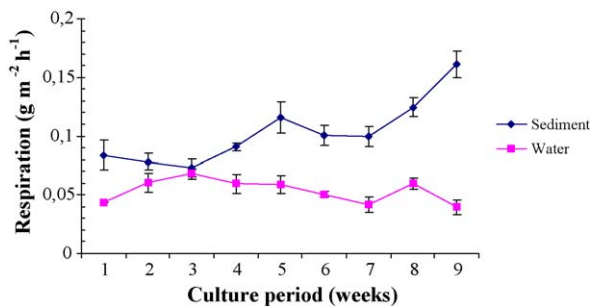


Fig. 2. Mean values of sediment and water respiration rates ( $\text{g O}_2 \text{m}^{-2} \text{h}^{-1}$ ) in shrimp *Litopenaeus vannamei* ponds during a culture of 9 weeks. Bars indicate standard error means.

unit, percentage of organic matter was determined in a pool of sediment from 12 sampling points at 30-cm depth. All analyses were done by Santa Catarina State Integrated Agriculture Development Agency (CIDASC), according to methodology by Embrapa/CNPT (2004).

### 2.3. Characterization of photosynthesis

To weekly monitor photosynthetic activity by changes in DO concentration in pond water samples incubated with and without light the clear and dark bottles method was used (Boyd and Tucker, 1992).

Because photosynthesis is affected by the incidence of light, pairs of dark and clear bottles (2-L bottles) were placed in two depths in the pond (surface and bottom). After the bottles were filled with pond water, they were incubated from 08:00 to 18:00 h. Three repetitions were done per pond, and sampling sites equal to those in Fig. 1.

### 2.4. Characterization of the temporal requirement of mechanical aeration

All respiration data were used to characterize temporal requirement of mechanical aeration ( $\text{HP ha}^{-1}$ ) in shrimp ponds. Total oxygen demand (OD) was calculated using the minimum, medium and maximum shrimp respiration (0.02, 0.08, and 0.16  $\text{mg O}_2 \text{L}^{-1} \text{h}^{-1}$ , respectively) described in the literature (Fast and Boyd, 1992), and the SR and WR obtained in the column method, as shown in the following equation:

$$\text{OD} = \text{ShR} + \text{WR} + \text{SR} \quad (2)$$

where OD is the oxygen demand ( $\text{mg L}^{-1} \text{h}^{-1}$ ); ShR the shrimp respiration rate ( $\text{mg L}^{-1} \text{h}^{-1}$ ); WR the water respiration rate ( $\text{mg L}^{-1} \text{h}^{-1}$ ) and SR is the sediment respiration rate ( $\text{mg L}^{-1} \text{h}^{-1}$ ).

Next, considering the pond total volume, OD was adjusted by the following equation:

$$\text{TOD} = \text{OD} V \times 10^{-3} \quad (3)$$

where TOD is the total oxygen demand ( $\text{kg h}^{-1}$ );  $V$  the volume of the pond ( $\text{m}^3$ ); and  $10^{-3}$  is the conversion factor.

Based on standard oxygen transfer rates for mechanical aerators available in the market, oxygen transfer rate at 20 °C was determined by the following equation:

$$\text{OTR}_{20} = \frac{\text{SOTR}(C_s - C_m)}{C_s} \quad (4)$$

where  $OTR_{20}$  is the oxygen transfer rate at 20 °C ( $\text{kg h}^{-1}$ );  $SOTR$  the standard oxygen transfer rate ( $\text{kg h}^{-1}$ );  $C_s$  the saturated oxygen concentration at 20 °C ( $\text{mg L}^{-1}$ ) and  $C_m$  is the minimum tolerated oxygen concentration ( $3 \text{ mg L}^{-1}$ ).

Then, oxygen transfer rate was adjusted to the mean temperature of the experimental units by the following equation:

$$OTR_T = OTR_{20} \times 1.024^{T-20} \quad (5)$$

where  $OTR_T$  is the oxygen transfer rate at pond temperature ( $\text{kg h}^{-1}$ ) and  $T$  is the pond temperature (°C).

After these calculations, aerations required by pond hectare ( $\text{HP ha}^{-1}$ ) for every week of the production cycle was determined using the following equation:

$$\text{Number of aerators} = \frac{\text{TOD}}{\text{OTR}_T} \quad (6)$$

### 2.5. Statistical analysis

ANOVA ( $P < 0.05$ ) was used to observe the WR, SR and photosynthesis behavior separately and throughout the 9 weeks of experiment. Tukey test was used to compare and assess means from all data collected. Correlation between WR and SR was checked by the  $t$ -student ( $P < 0.05$ ) parametric test.

## 3. Results

### 3.1. Sediment and water column respiration rates

Comparing SR and WR, sediment respiration rates were the highest, reaching values as high as four times the water column respiration rates ( $0.16 \pm 0.01$  and

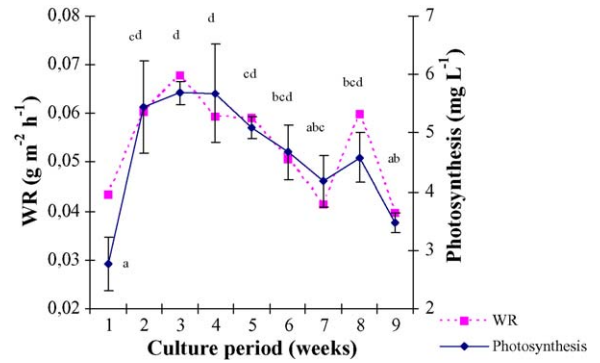


Fig. 3. Mean water respiration rates (WR,  $\text{g O}_2 \text{ m}^{-2} \text{ h}^{-1}$ ) and photosynthesis ( $\text{mg O}_2 \text{ L}^{-1}$ ) in three shrimp *L. vannamei* ponds during the culture period. In photosynthesis, bars indicate standard error; letters indicate significant difference between mean values ( $P < 0.05$ ).

$0.04 \pm 0.006 \text{ g m}^{-2} \text{ h}^{-1}$ , respectively). Except for the third week of culture, there were significant differences ( $P < 0.05$ ) between SR and WR. Such differences are evident in Fig. 3, where it can be seen that water and sediment respiration patterns were opposite to each other in certain weeks. During the first weeks, WR tended to increase and SR to decrease, whereas in the last weeks (eighth and ninth weeks) this pattern was inverted.

SR values showed an almost constant value ( $0.07 \pm 0.007$  to  $0.16 \pm 0.01 \text{ g m}^{-2} \text{ h}^{-1}$ ) during the observation period, and the maximum respiration rate occurred on the ninth week, which was significantly different ( $P < 0.05$ ) from the other weeks. Nevertheless, SR was not linear with increasing and decreasing periods throughout the culture period (Table 1). Similar to SR, concentration of organic matter in the sediment also increased. At the beginning of the culture, the mean concentration of organic matter in the sediment was of 3.4%, but at the end of the

Table 1

Mean values for shrimp weight (MSW), shrimp respiration rate (ShR), water respiration rate (WR) and sediment respiration rate (SR), ponds total oxygen demand (TOD), estimate aeration power (EP) and power used at Yakult Experiment Farm (PY) throughout the 9-week culture period

| Weeks | MSW (g)    | Respiration rate ( $\text{g O}_2 \text{ m}^{-2} \text{ h}^{-1}$ ) |                  |                   | TOD ( $\text{kg h}^{-1}$ ) | EP ( $\text{HP ha}^{-1}$ ) | PY ( $\text{HP ha}^{-1}$ ) | Surplus (PY–EP) |
|-------|------------|-------------------------------------------------------------------|------------------|-------------------|----------------------------|----------------------------|----------------------------|-----------------|
|       |            | ShR <sup>a</sup>                                                  | WR               | SR                |                            |                            |                            |                 |
| 1     | 2.5 ± 0.4  | 0.02                                                              | 0.04 ± 0.000 ab  | 0.08 ± 0.043 ab   | 1.76 ± 0.15                | 1.08 ± 0.05                | 1.7                        | +0.62           |
| 2     | 4.7 ± 0.7  | 0.02                                                              | 0.06 ± 0.008 bc  | 0.08 ± 0.060 ab   | 1.90 ± 0.15                | 1.16 ± 0.04                | 3.3                        | +2.14           |
| 3     | 5.4 ± 0.6  | 0.02                                                              | 0.07 ± 0.005c    | 0.07 ± 0.068 a    | 1.93 ± 0.15                | 1.18 ± 0.04                | 5.0                        | +3.82           |
| 4     | 6.3 ± 1.1  | 0.08                                                              | 0.06 ± 0.008b c  | 0.09 ± 0.059 abc  | 2.76 ± 0.08                | 1.68 ± 0.02                | 5.0                        | +3.32           |
| 5     | 7.7 ± 0.9  | 0.08                                                              | 0.06 ± 0.008b c  | 0.12 ± 0.059 cd   | 3.06 ± 0.22                | 1.86 ± 0.07                | 5.0                        | +3.14           |
| 6     | 9.0 ± 1.2  | 0.08                                                              | 0.05 ± 0.002 abc | 0.10 ± 0.051 bcd  | 2.78 ± 0.09                | 1.68 ± 0.03                | 5.0                        | +3.32           |
| 7     | 9.7 ± 1.6  | 0.16                                                              | 0.04 ± 0.007 a   | 0.10 ± 0.042 abcd | 3.61 ± 0.18                | 2.20 ± 0.06                | 5.0                        | +2.80           |
| 8     | 10.8 ± 0.9 | 0.16                                                              | 0.06 ± 0.005 bc  | 0.12 ± 0.060 d    | 4.13 ± 0.04                | 2.50 ± 0.01                | 5.0                        | +2.50           |
| 9     | 12 ± 1.2   | 0.16                                                              | 0.04 ± 0.006 a   | 0.16 ± 0.040 e    | 4.33 ± 0.19                | 2.62 ± 0.06                | 5.0                        | +2.38           |

MSW, WR, SR, TOD and EP are represented as means ± S.E. Different letters in WR and SR indicate significant difference between lines of the same column ( $P < 0.05$ ).

<sup>a</sup> ShR (minimum 0.02, mean 0.08, and maximum 0.16) was taken from literature (Fast and Boyd, 1992).

experiment period, this concentration had increased (6.3%), as did the sediment respiration.

WR did not vary much ( $0.04 \pm 0.006$  to  $0.07 \pm 0.005 \text{ g m}^{-2} \text{ h}^{-1}$ ), and significant difference was not observed between the first and last week of experiment. Similar to SR, WR was not linear during the experiment period, even dropping in the last week of culture (Table 1). Photosynthesis pattern was similar to WR, increasing at the beginning of the culture and decreasing at the end, and there was no significant difference ( $P > 0.05$ ) between the first and the last week of experiment (Fig. 4).

As for water quality parameters (Fig. 4), salinity, oxygen, temperature, and pH were kept within adequate levels for *L. vannamei* culture throughout the experiment. On the other hand, water transparency decreased abruptly between the first and second weeks and became more stable on the following weeks. Mean dissolved oxygen concentrations were always above  $4 \text{ mg L}^{-1}$ .

### 3.2. Characterization of temporal mechanical aeration requirement

Aeration requirement for a culture cycle was characterized based upon SR, WR and shrimp *L. vannamei* respiration rates. Mean values for total oxygen demand (TOD) and aeration requirements in three ponds for every week of experiment are in Table 1.

Aeration results are clearly related to TOD and higher aeration ( $2.62 \pm 0.06 \text{ HP ha}^{-1}$ ) is required in the

last week of culture. However, only the calculation of aeration for the first week of culture ( $1.08 \pm 0.05 \text{ HP ha}^{-1}$ ) was close to the power used at Yakult Experiment Farm (UFSC), equivalent to  $1.7 \text{ HP ha}^{-1}$ . On the second week, aeration used in each pond ( $3.3 \text{ HP ha}^{-1}$ ) was practically double of the estimate ( $1.16 \pm 0.04 \text{ HP ha}^{-1}$ ). From the third week on, when ca.  $5 \text{ HP ha}^{-1}$  was used, calculated values were even more discrepant from those used at Yakult Experiment Farm, differences being higher on the third, fourth and sixth weeks of culture (Table 1).

## 4. Discussion

In aquaculture ponds it is known that several factors can affect sediment characteristics and, consequently, respiration rates. In studies that characterize sediment respiration rate (SR), it was observed that it can vary according to the area studied, type of culture and methodology used. Furthermore, according to Berthelson et al. (1996), SR can be heterogeneous inside one single pond and differences can be related to intensity of currents caused by aerators and by the wind, and to feeding practices. Thus, in the present study, assays were done in triplicate and sampling points were strategically placed in the ponds to homogeneously represent the SR of the experiment units. In addition, little variation of the results may be due to the fact that the experiment units presented the same characteristics.

In this study, SR values ( $0.07\text{--}0.16 \text{ g m}^{-2} \text{ h}^{-1}$ ) characterized during a production cycle were within the range of results mentioned in the review by Avnimelech and Ritvo (2003), which was of  $0.01\text{--}5.3 \text{ g m}^{-2} \text{ h}^{-1}$ . However, values mentioned by these authors refer to sediment respiration in ponds with a great diversity of aquacultured organisms. In fresh water and salt water shrimp ponds, mean SR of approximately  $0.23$  and  $0.29 \text{ g m}^{-2} \text{ h}^{-1}$ , respectively (Madenjian et al., 1987; Madenjian, 1990) were observed. According to Garcia and Brune (1991), in ponds without aeration and a density of  $5 \text{ shrimp m}^{-2}$ , maximum SR was of  $0.04 \text{ g m}^{-2} \text{ h}^{-1}$ , whereas in ponds with aeration and densities between  $20$  and  $200 \text{ shrimp m}^{-2}$ , mean SR was about  $0.06 \text{ g m}^{-2} \text{ h}^{-1}$ .

Although nutrients play an important role in the growth of cultured aquatic organisms, accumulation in excess can severely impact water quality, the development of benthic community and, consequently, nutrient recycling (Yuvanatemiyia and Boyd, 2006). Usually, in shrimp and fish ponds, organic matter concentration and SR tend to increase with time of culture, pond depth and useful life (Ritvo et al., 1998; Steeby et al., 2004a,b). In

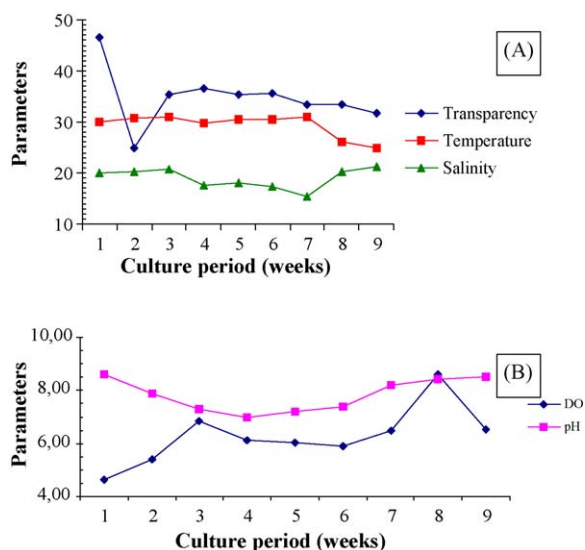


Fig. 4. Mean values of water quality parameters in three shrimp *L. vannamei* ponds during a culture period. (A) Transparency (cm), temperature ( $^{\circ}\text{C}$ ) and salinity ( $\text{‰}$ ). (B) pH and dissolved oxygen, DO ( $\text{mg L}^{-1}$ ).

this study a similar pattern was observed for time of culture, when SR doubled from the beginning to the end of the production cycle. Suplee and Cotner (1996) verified the same behavior in shrimp ponds, but SR increased almost four times from the third week until the end of culture, a variation from  $0.06$  to  $0.24 \text{ g m}^{-2} \text{ h}^{-1}$ . Using the column method in fish ponds (*Cyprinus carpio*), Shapiro and Zur (1981) also reported increase in SR values, which were of  $0$ – $0.09$  and of  $0$ – $0.05 \text{ g m}^{-2} \text{ h}^{-1}$ , for densities of  $20,000$  and  $7000 \text{ fish ha}^{-1}$ , respectively. In *I. punctatus* ponds, Steeby et al. (2004a) observed a mean SR of  $0.48 \text{ g m}^{-2} \text{ h}^{-1}$  and the large variation of the results ( $0.06$ – $0.96 \text{ g m}^{-2} \text{ h}^{-1}$ ) was attributed mainly to the daily DO variation, characteristics of the ponds, and management practices.

Analyses of the sediment indicated increase in the concentration of organic matter from the begin to the end of the culture period (from  $3.4$  to  $6.3\%$ ). This has possibly resulted in higher demand of oxygen by decomposing bacteria, favored by the high summer temperatures and, consequently elevated the SR at the end of experiment. Xinglong and Boyd (2006) reported that carbon dioxide and biological oxygen demand increase with the increase in the concentration of organic matter. The study by Martinez-Cordova et al. (2002) also showed such behavior in *L. stylirostris* ponds ( $20 \text{ shrimp m}^{-2}$ ) fed with two different diets. Despite both diets were given according to daily consumption, final concentrations of organic matter ( $2.78$  and  $3.63\%$ ) were lower than those observed in our study. On the other hand, Suplee and Cotner (1996) verified that at the end of a culture period the sediment surface of *L. vannamei* ponds ( $21 \text{ shrimp m}^{-2}$ ) was highly enriched by organic compounds ( $8$ – $15\%$ ). Considering that the studies mentioned above used very similar stocking densities, probably the main factor acting on sediment quality was pond management.

The non-linear pattern of the respiration data found in this study also suggests that pond management influenced SR. During the first weeks SR was lower supposedly because benthic biomass was partially exhausted due to management practices (disinfection, oxidation and mineralization of the organic matter in the sediment) adopted in the beginning of the culture. On the seventh week, low SR was probably due to high water change (approximately  $40\%$  of pond volume in one day), with consequent suspension and removal of organic matter from the culture pond. In the last 2 weeks, when liming of ponds was done, SR increased again, possibly due to the settlement of organic matter and phytoplankton suspended in the water column by the addition of calcium carbonate ( $\text{CaCO}_3$ ).

Opposite to SR, WR was low at the end of the culture period, with no significant difference from the value registered on the first week of culture. Usually WR is proportional to the incidence of phytoplankton and it is basically due to the respiration of microalgae in the absence of light. Heavy rain during the last 2 weeks of culture may have killed the phytoplankton and, consequently, decreased WR.

Studies in shrimp ponds show that phytoplankton productivity can vary widely due to some factors. Buford (1997) analyzed primary productivity in shrimp ponds during 6 months and reported that it was affected by light, pond depth and water turbidity. According to the same author, heavy rain during culture periods can increase water turbidity, which blocks light penetration and decreases phytoplankton biomass. In the review by Alonso-Rodríguez and Páez-Osuna (2003), it is reported that in shrimp ponds in Mexico phytoplankton population varied widely in quantity, so that both decrease and increase of microalgae density were observed at the end of production cycles. According to these authors, wide variation in phytoplankton proves the influence of feeding management, fertilization, water exchange rate and quality of water source on the microalgae density.

Supply water at Yakult Experiment Farm (UFSC) was highly transparent on the first week of culture, indicating low microalgae density. This can be confirmed by the low values for gross photosynthesis, with minimum of  $0.28 \text{ mg L}^{-1} \text{ h}^{-1}$  on the first week of the production cycle. Maximum photosynthesis occurred during the third and fourth weeks of culture ( $0.57 \text{ mg L}^{-1} \text{ h}^{-1}$ ), period when water transparency began to stabilize. In the study by Buford et al. (2003) in an intensive shrimp culture ( $120 \text{ shrimp m}^{-2}$ ) without water exchange in Belize, primary productivity values ( $1.42$ – $5.06 \text{ mg L}^{-1} \text{ h}^{-1}$ ) were much higher than those found in this study. Along et al. (1999) reported that in an extensive shrimp culture in Vietnam gross primary productivity varied between  $0.32$  and  $4.67 \text{ mg L}^{-1} \text{ h}^{-1}$ .

According to a study by Boyd (2001) in channel catfish (*I. punctatus*) ponds, most of the oxygen in the environment was produced by photosynthesis and consumed by phytoplankton respiration. In shrimp ponds in Texas, the same situation was reported by Garcia and Brune (1991).

In our study, the relationship between phytoplankton oxygen production and consumption can be observed analyzing the photosynthesis and WR patterns. Similar to WR, photosynthesis increased in the first weeks and decreased at the end of the production cycle, suggesting that primary productivity and WR are proportional to phytoplankton density. In addition, WR was low and did

not vary between the first and the last week of culture ( $0.04 \text{ g m}^{-2} \text{ h}^{-1}$ ), when compared to SR values. In the same way, Shapiro and Zur (1981) verified low water respiration in fish ponds, whereas Barry et al. (1984) reported that water respiration ( $0.02\text{--}0.31 \text{ g m}^{-2} \text{ h}^{-1}$ ) was higher than in the sediment ( $0.01\text{--}0.04 \text{ g m}^{-2} \text{ h}^{-1}$ ) in *Macrobrachium rosenbergii* ponds.

As for the characterization of aeration requirement, higher aeration was required on the last week of culture ( $2.62 \pm 0.06 \text{ HP ha}^{-1}$ ). It was also observed that the aeration used at Yakult Experiment Farm was over the estimations for the entire culture period. Multiplying the surplus of aeration per week by the number of days of culture (63 days) there is an excess of  $168.26 \text{ HP ha}^{-1}$ , which certainly increases production costs in terms of electricity expenses. This surplus per hectare may be explained by the fact that most shrimp farmers in Santa Catarina state exceed the actual aeration requirement so as to guarantee a successful culture.

## 5. Conclusions

Results show that in *L. vannamei* culture ponds, both total oxygen demand and aeration requirements increase with time. In general, aeration requirements estimated for every week based in total demand oxygen was lower than the aeration observed in other ponds of the same farm. Correct calculation of aeration requirements for each week of culture can represent substantial savings with electricity and consequently reduce total production costs.

## Acknowledgements

This study was done with the help of Prof. Walter Seiffert, employees and trainees at Yakult Experiment Farm, Universidade Federal de Santa Catarina. We would like to thank Bernauer Aquacultura Ltd. for providing the equipment and Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES), from the Ministry of Education, for granting scholarship for the first author.

## References

- Along, D.M., Dixon, P., Johnston, D.J., Tien, D.V., Xuan, T.T., 1999. Pelagic processes in extensive shrimp ponds of the Mekong delta, Vietnam. *Aquaculture* 175, 121–141.
- Alonso-Rodríguez, R., Páez-Osuna, F., 2003. Nutrients, phytoplankton and harmful algal blooms in shrimp ponds: a review with special reference to the situation in the Gulf of California. *Aquaculture* 219, 317–336.
- Avnimelech, Y., Ritvo, G., 2003. Shrimp and fish pond soils: processes and management. *Aquaculture* 220, 549–569.
- Barry, A., Costa-Pierce, D.B., Craven, D.M., Laws, K., Laws, A.E., 1984. Correlation of in situ respiration rates microbial biomass in prawn (*Macrobrachium rosenbergii*) ponds. *Aquaculture* 37, 157–168.
- Berthelson, C.R., Cathcart, T.P., Pote, J.W., 1996. In situ measurement of sediment oxygen demand in catfish ponds. *Aquac. Eng.* 15, 261–271.
- Boddeke, R., 1983. Survival strategies of Penaeid shrimps and their significance for shrimp culture. In: Rogers, G.L., Day, R., Lim, A. (Eds.), *Proceedings of the First International Conference on Warm Water Aquaculture-Crustacea*. Brigham Young University Hawaii Campus, Laie, HI.
- Bowman, G.T., Delfino, J.J., 1980. Sediment oxygen demand techniques: a review and comparison of laboratory and in situ systems. *Water Res.* 14, 491–499.
- Boyd, C.E., 1990. *Water Quality in Aquaculture Ponds*. Alabama Agricultural Experiment Station, Auburn University, AL, p. 442.
- Boyd, C.E., 1995. *Bottom Soils, Sediment, and Pond Aquaculture*. Chapman & Hall, New York, p. 348.
- Boyd, C.E., 2001. Manejo da qualidade da água na aquicultura e no cultivo do camarão marinho. *Associação Brasileira de Criadores de Camarão-ABCC*, Recife, PE, p. 157.
- Boyd, C.E., Tucker, C.S., 1979. Emergency aeration of fish ponds. *Trans. Am. Fish. Soc.* 108, 299–306.
- Boyd, C.E., Tucker, C.S., 1992. *Water Quality and Pond Soil Analyses for Aquaculture*. Alabama Agricultural Experiment Station, Auburn University.
- Braathem, P.C., 1983. Variação na concentração de oxigênio dissolvido em tanques da estação de hidrologia e piscicultura de Viçosa. *Revista CERES* 3 (169), 170–188.
- Buford, M.A., 1997. Phytoplankton dynamics in shrimp ponds. *Aquac. Res.* 28 (5), 351–360.
- Buford, M.A., Thompson, P.J., McIntosh, R.P., Barman, R.H., Pearson, D.C., 2003. Nutrient and microbial dynamics in high-intensity, zero-exchange shrimp ponds in Belize. *Aquaculture* 219, 393–411.
- Davis, W.S., Lathrop-Davis, J.E., 1986. Brief history of sediment oxygen demand investigations. In: Hatcher, K.J. (Ed.), *Sediment Oxygen Demand: Processes, Modeling and Measurement*. University of Georgia Institute of Natural Resources, Athens, pp. 9–21.
- Embrapa/CNPQ, 2004. *Interpretação conforme recomendações de adubação e calagem para os estados do Rio Grande do Sul e de Santa Catarina*, 10th ed., SBSCS, Núcleo Regional Sul.
- Engle, C.R., Hatch, U., 1988. Economic assessment of alternative aquaculture aeration strategies. *J. World Aquac. Soc.* 19 (3), 85–86.
- Fast, A., Boyd, C., 1992. Water circulation, aeration and other management practices. In: Fast, A., e Lester, J. (Eds.), *Marine Shrimp Culture: Principles and Practices*. Elsevier Science Publishers, Amsterdam, pp. 457–495.
- Garcia, A., Brune, D.E., 1991. Transport limitation of oxygen in shrimp culture ponds. *Aquac. Eng.* 10, 269–279.
- Madenjian, C.P., 1990. Patterns of oxygen production and consumption in intensively managed marine shrimp ponds. *Aquac. Fish. Manage.* 28, 407–417.
- Madenjian, C.P., Rogers, G.L., Fast, A.W., 1987. Predicting night time dissolved oxygen loss in prawn ponds of Hawaii. Part II. A new method. *Aquac. Eng.* 6, 209–225.
- Martinez-Cordova, L.R., Campaña-Torres, A., Porchas-Cornejo, M.A., 2002. Promotion and contribution of biota in low water

- exchange ponds farming blue shrimp *Litopenaeus stylirostris*. Aquac. Res. 33, 27–32.
- Munsiri, P., Boyd, C.E., Teichert-Coddington, D., Hajek, B.F., 1996. Texture and chemical composition of soils from shrimp ponds near Choluteca, Honduras. Aquac. Int. 4, 157–168.
- Peterson, E.L., Muir, P.R., 1999. Round Ponds Dynamics. Book of Abstracts, World Aquaculture. World Aquac. Soc, Baton Rouge, LA, p. 597.
- Porcella, D.B., Mills, W.B., Bowie, G.L., 1986. A review of modeling formulations for sediment oxygen demand. In: Hatcher, K.J. (Ed.), Sediment Oxygen Demand: Processes, Modeling, and Measurement. University of Georgia Institute of Natural Resources, Athens, pp. 121–138.
- Ritvo, G., Dixon, J.B., Lawrence, A.L., Neill, W.H., Speed, M.F., 1998. Accumulation of chemical elements in Texas shrimp pond soils. J. World Aquac. Soc. 29, 422–431.
- Sharp, J., 1976. Effects of dissolved oxygen, temperature, and weight on respiration of *Macrobrachium rosenbergii*. In: Knight, A.W. (Ed.), Laboratory Studies on Selected Nutritional, Physical, and Chemical Factors Effecting the Growth, Survival, Respiration, and Bioenergetics of the Giant Prawn, *Macrobrachium rosenbergii*. Water Si. and Eng. Paper 4501, Univ. Calif., Davis.
- Shapiro, J., Zur, O., 1981. A simple *in situ* method for measuring benthic respiration. Water Res. 15, 283–285.
- Steeby, J., Hargreaves, J., Tucker, C., Cathcart, T., 2004a. Modeling industry-wide sediment oxygen demand and estimation of the contribution of sediment to total respiration in commercial channel catfish ponds. Aquac. Eng. 31, 247–262.
- Steeby, J., Hargreaves, J., Tucker, C., 2004b. Factors affecting sediment oxygen demand in commercial channel catfish ponds. J. World Aquac. Soc. 35, 322–334.
- Suplee, M.W., Cotner, J.B., 1996. Temporal changes in oxygen demand and bacterial sulfate reduction in inland shrimp ponds. Aquaculture 145, 141–158.
- Xinglong, J., Boyd, C.E., 2006. Relationship between organic carbon concentration and potential pond bottom soil respiration. Aquac. Eng. 35 (2), 147–151.
- Yuvanatemiy, V., Boyd, C.E., 2006. Physical and chemical changes in aquaculture pond bottom soil resulting from sediment removal. Aquac. Eng. 35 (2), 199–205.