The use of oysters as natural filters of aquaculture effluent

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CSIRO
AUSTRALIA

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RESEARCH &
DEVELOPMENT
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Marine Botany
The University of Queensland

Project number 94/132

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NON-TECHNICAL SUMMARY

94/132 The use of oysters as natural filters of aquaculture effluent

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Keywords: Oyster filtration, prawn pond effluent, treatment, and water quality

SUMMARY

This study was initiated by prawn farmers and oyster growers in Moreton Bay, Queensland. The primary objective was to explore the potential of growing oysters in the discharge canals of prawn farms. Growing oysters in this way was seen to have potential benefits for both industries. Prawn farmers were interested in the potential of using oysters to filter waste nutrients from the prawn pond effluent prior to re-circulation or discharge. The oyster farmers were interested in the potential to enhance the growth and condition of oysters using the high phytoplankton biomass in prawn pond effluent. The objectives of the study were to:

- Quantify the biofiltration capacity of Sydney rock oysters (*Saccostrea commercialis*) and their effects on the water quality of aquaculture pond effluent.

- Determine the relative growth and condition of Sydney rock oysters grown in pond effluent channels and traditional oyster leases.

The main findings of the study were:

- Oyster filtration can significantly reduce the concentrations of total suspended solids, bacteria, phytoplankton, nitrogen and phosphorus (particulate and dissolved) in pond effluent.
- Recirculating systems can improve the effectiveness of the removal of pond wastes by oyster filtration.
- High concentrations of suspended inorganic particles in pond effluent inhibit the filtration rates and growth of oysters.
- The effectiveness of oyster filtration of pond effluent could be enhanced if the effluent were pre–treated in a settling pond to permit settlement of inorganic particles.

The results of our study indicate that the use of oysters may be most effective if incorporated into integrated effluent management and treatment systems. These systems would need to promote a reduction in suspended inorganic particles by sedimentation prior to oyster filtration. The processes within the systems would also need to be well enough understood to permit sufficient water quality control for the conversion of waste nutrients to cash crops such as oysters, fish or macroalgae.

The design and operation of prawn pond effluent treatment systems are at an early stage of development in Australia (Preston *et al.*, 1997, Jones & Preston, 1999) and elsewhere (Teichert-Coddington *et al.*, 1999). Most of the systems that have been evaluated to date involve the use of treatment ponds. These ponds permit settlement of suspended inorganic and organic matter, the filtration of suspended matter by naturally occurring filter feeders (eg barnacles and tube worms) and uptake of dissolved nutrients by phytoplankton and other marine flora including filamentous and benthic algae. The current reliance on natural biota reflects the fact that these systems are still under development. Although treatment ponds can be effective in effluent nutrient reduction, the biological and chemical processes within the ponds are poorly understood. Once these systems are better understood, it is likely that prawn farm managers will be able to convert a proportion of effluent nutrients to cash crops such as oysters and macroalgae. The results of our study indicate that, in a well-designed treatment system, Sydney rock oysters could provide an effective means of improving effluent water quality and recapturing otherwise wasted nutrients.

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BACKGROUND

In prawn farming, the addition of feeds and action of pond aerators can result in increased sediment nutrient and loads in pond effluent compared to the influent (Phillips & Beveridge, 1993; Briggs & Funge-Smith, 1994). Consequently, there are concerns about adverse environmental impacts on coastal waters due to increased turbidity and eutrophication (Ziemann *et al.*, 1992; Hopkins *et al.*, 1993) and there is a need to develop more effective controls of the quality of effluent water prior to discharge into the environment or recirculation (Phillips & Beveridge, 1993; Primavera, 1994).

One potential method of reducing adverse environmental impacts, and recapturing otherwise wasted nutrients is to use bivalves to filter the pond effluent (Lin *et al.*, 1993; Lin, 1995). Pond effluent contains organic matter including bacteria, phytoplankton, and detritus (Ziemann *et al.*, 1992) that could provide food for bivalves such as oysters (Hopkins *et al.*, 1993). Pond effluent can also contain a high proportion of small inorganic particles (Hopkins *et al.*, 1995) that could be removed from suspension by oyster filtration and subsequently expelled as larger, more settleable, particles in the form of pseudofaeces (Tenore & Dunstan, 1973).

NEED

With the expansion of pond aquaculture sites in Australia, both industry and government resource managers are becoming increasingly aware that the industry needs to develop methods of improving effluent management and minimising adverse environmental impacts. Some industry members also have the additional concern that a proportion of the valuable pelleted feeds added to ponds is degraded and lost via pond effluent. It could be of considerable benefit to recover some of the waste nutrients rather than discharging them into natural waterways.

The removal of sediment from pond effluent could probably be achieved by structural changes to effluent channels such as the use of baffles. The removal of nutrients, microalgae and other material could be achieved using sewage treatment methods but this would be prohibitively expensive. For example, Rubel and Hager (1980) determined that reducing the levels of TSS by use of filtering apparatus would cost $45 656/acre (capital) and $30 364/acre (annual operating costs). A more cost-effective alternative is the use of bivalves as natural biofilters (Hopkins *et al.*, 1993). These have the additional benefit of providing a secondary source of farm income.

Prawn farmers and oyster growers in the Moreton Bay region in southeastern Queensland initiated the research described in this report. The main species of prawns farmed in the region are the giant tiger prawn (*Penaeus monodon*) and the Kuruma prawn (*Penaeus japonicus*). The oyster species grown on traditional leases is the Sydney rock oyster (*Saccostrea commercialis*). During the 1991/92 prawn farm production season Moreton Bay Prawn Farm trialled the cultivation of Sydney rock oysters, supplied buy a local oyster grower, in prawn pond discharge channels. Discussions with the local oyster grower indicated that growth rates and oyster condition were better than those of oysters grown on the oyster leases in Moreton Bay. There was no problem with QX disease which, in the past, has proved a problem for Moreton Bay oyster farmers (Witney *et al.*,1988). Hence, at the outset of this project, there appeared to be the potential for commercial benefit from growing oysters in prawn pond effluent channels. Information was also needed about the effects of oysters on pond effluent water quality. The objectives of this study were, therefore, to quantitatively assess the efficiency of Sydney rock oysters in removing nutrients, bacteria, phytoplankton and other particulate organic matter from the effluent water of prawn ponds. The project also examined the growth of oysters grown in pond effluent compared with those grown on traditional oyster leases in Moreton Bay.

TECHNICAL REPORT – PROJECT IN DETAIL

The effect of oysters on effluent water quality

Introduction

In this component of the study we investigated effects of oyster filtration on prawn farm effluent water quality. The locations of the prawn farm (Moreton Bay Prawn Farm) and the lease that provided the oysters are shown in figure 1.

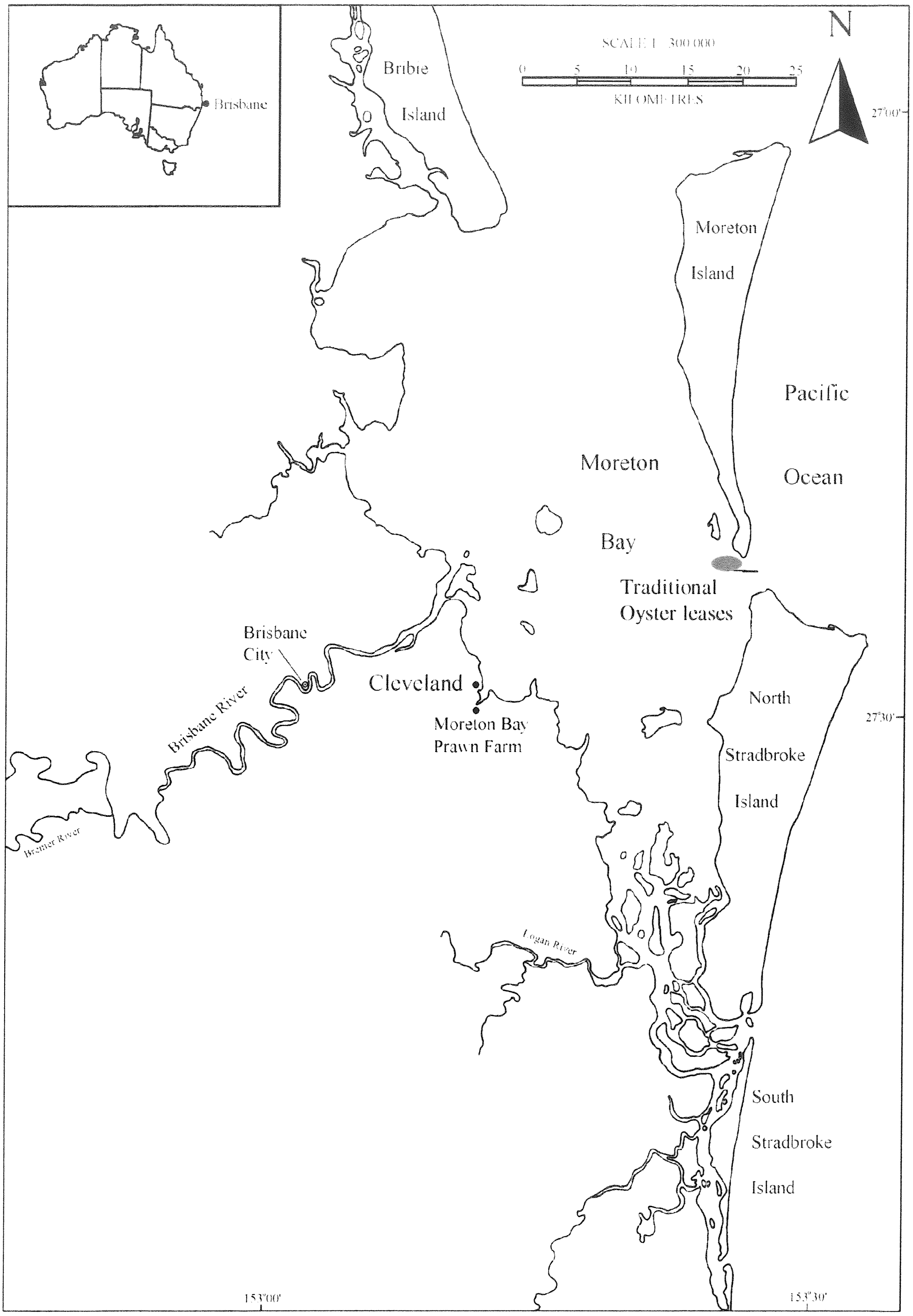


Figure 1. Location of the prawn farm and oyster lease study sites in Moreton Bay

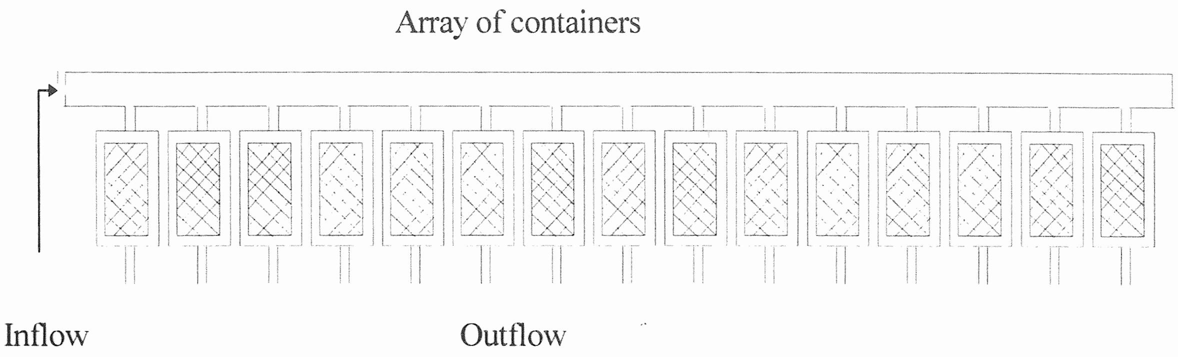
In Moreton Bay, prawn farming and oyster cultivation are seasonal activities. In winter (June to August) prawn ponds are empty and Moreton Bay oysters are generally not harvested due to their poor condition. In spring (September to November) prawn ponds are fertilised to promote phytoplankton growth and ponds are stocked with prawn post-larvae. Oyster growth and conditioning occurs during spring and summer when phytoplankton densities in the bay increase (Dennison et al., 1993). Oyster growth to marketable size takes 2 to 3 years (Witney, et al., 1988). Previous studies have demonstrated that placing oysters directly into prawn ponds results in problems with fouling and interference with the management of the prawn ponds (Hopkins et al., 1993). In this study our approach was to stock oysters in tanks or raceways supplied with water pumped from the effluent canal of Moreton Bay Prawn Farm during the production season when the farm ponds were stocked with prawns (*Penaeus japonicus*). In the first of a series of experiments we examined the effects of oyster density on pond effluent water quality. In this experiment the effects of oyster filtration were examined in still water, representing periods when there is no flow-through in the effluent canal.

Filtration in static water - the effects of oyster density

Materials and Methods

The effects of oyster filtration on shrimp pond effluent were determined by monitoring the inflow and outflow water in a raceway consisting of 15 plastic 34 l containers stocked with oysters (Fig. 2). Each raceway was supplied with water pumped directly from the effluent channel of Moreton Bay Prawn Farm. The effluent channel received water from 6 x 1 ha ponds with a stocking density of approximately 25 shrimp m^2 (*P. japonicus*). At the time of the experiments the mean wet weight of the shrimp was approximately 10 g.

The 15 containers were stocked with oysters (*S. commercialis*), the mean wet weight of individual oysters was 55g. In the experimental design, combinations of live and dead oysters were used to produce 3 different densities of live oysters; low, medium and high plus one treatment of dead oysters (Table 1). There were 3 replicates for each density of oysters, and a control treatment of no oysters (to quantify the effects of sedimentation alone).


Array of containers

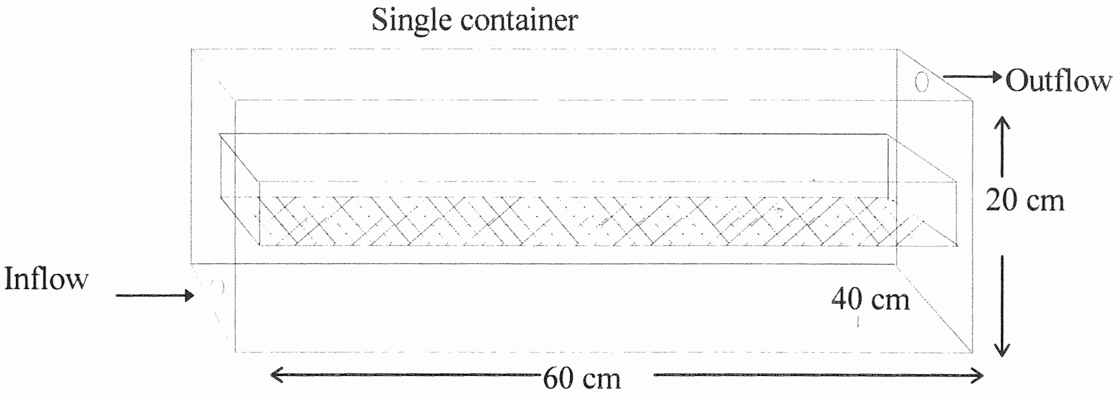

Single container

Figure 2. Schematic of containers used for holding the oysters.

Table 1. Combinations of live and dead oysters (*Saccostrea commercialis*) used in experiments to determine the effects of oyster density on the water quality of shrimp pond effluent

Treatment	**Description**
Control	no oysters
Shells	24 dead oysters
Low Density Treatment	8 live oysters and 16 dead
Medium Density Treatment	16 live oysters and 8 dead
High Density Treatment	24 live oysters

The inflow water samples were collected at the start of the experiment, and the outflow samples, after a 2 hour period during which the oysters were filtering the effluent (no water flow). Sampling consisted of collecting 3 replicate 1-L containers of water from the inflow pipe and from the outflow point of each of the 15 raceways. The water samples were returned to the laboratory where they were filtered for total suspended solids (TSS) calculation and chlorophyll *a* extraction. Sub-samples were taken for total N and P, bacterial numbers, and determination of the organic/inorganic ratio.

Total suspended solids (TSS) concentrations were determined by filtering a known volume of water onto a pre-weighed and pre-combusted (110 °C; 24 h) Whatman GF/C glass fibre filter. The filter was then oven dried at 110 °C for 24 h and TSS calculated by comparing the initial and final weights. The organic/inorganic ratio of the TSS was then determined by combustion of the organic material in a muffle furnace for 2 h at 235 °C and then for 3 h at 525 °C. Chlorophyll *a* was determined by filtering a known volume of water sample through Whatman GF/C filters that were immediately frozen. Acetone extraction and calculation of chlorophyll *a* concentration were done using the methods of Clesceri *et al.* (1989), and Parsons *et al.* (1989). Bacteria samples were stained with acridine orange and counted using an epifluorescence microscope (Hobbie, 1977). Unfiltered samples for nutrient analysis (total Kjeldahl nitrogen and total phosphorus) were collected in 120 ml polycarbonate vials, immediately frozen and subsequently analysed by the Queensland Government Chemical Laboratories using a Skalar autoanalyser.

Variation in the water quality parameters was examined using single factor analysis of variance (ANOVA).

Results

Oysters were effective in removing total suspended solids from pond effluent with significant reductions at each of the oyster densities and no significant reduction in the control treatments (Fig. 3). The reduction in effluent TSS varied with oyster density. At the high density the concentration of TSS was reduced to 49% of the initial level in the pond effluent, a significantly greater reduction than at the low-density treatment (80%).

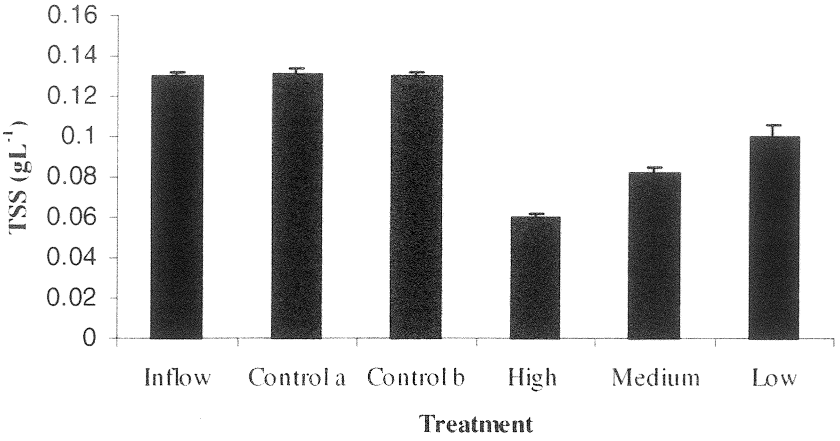


Figure 3. The effects of oyster density on the reduction of total suspended solids (TSS) in prawn pond effluent. Inflow: untreated effluent, control a: no oysters, control b: oyster shells only.

Table 2. Concentration of various water quality parameters before and after filtration by oysters at 3 different densities (see Table 1). Values for control (no oysters) and shells (dead shells only) are also given. Values in brackets are concentrations expressed as a percentage of the inflow value. * $p \leq 0.05$; ** $p \leq 0.01$; *** $p \leq 0.001$. ^{abc} mean values with different letters are significantly different at $p < 0.05$. Values in italics are standard errors.

Treatment	TSS g.l^{-1}	Organic g.l^{-1}	Inorganic g.l^{-1}	Total N mg.l^{-1}	Total P mg.l^{-1}	Bacteria no./ml× 10^{6}	Chl *a* µg.l^{-1} (%)
Inflow	0.13^{a}	0.035^{a}	0.091^{a}	1.40^{ab}	0.15^{ab}	22.8^{a}	44.1^{a}
	0.0052	*0.0007*	*0.004*	*0.00*	*0.00*	*1.35*	*4.1*
Control	0.13^{a} (100)	0.038^{a} (110)	0.089^{a} (97)	1.46^{a} (104)	0.16^{ab} (107)	18.9^{a} (83)	16.9^{b} (38)
	0.0019	*0.004*	*0.003*	*0.04*	*0.008*	*1.01*	*1.03*
Shells	0.13^{a} (100)	0.036^{a} (104)	0.091^{a} (99)	1.53^{a} (110)	0.17^{a} (116)	19.5^{a} (85)	20.8^{b} (47)
	0.002	*0.0006*	*0.002*	*0.04*	*0.006*	*0.73*	*0.51*
Low	0.10^{ab} (80)	0.033^{a} (95)	0.068^{b} (75)	1.24^{ab} (89)	0.15^{ac} (101)	20.9^{a} (92)	13.6^{bc} (31)
	0.007	*0.04*	*0.004*	*0.15*	*0.02*	*1.09*	*0.64*
Medium	0.08^{bc} (64)	0.025^{ab} (71)	0.056^{bc} (62)	1.23^{ab} (88)	0.12^{bcd} (83)	19.2^{a} (84)	8.3^{cd} (19)
	0.002	*0.0006*	*0.001*	*0.04*	*0.004*	*0.8*	*0.53*
High	0.06^{c} (49)	0.018^{b} (52)	0.043^{c} (47)	1.12^{b} (80)	0.10^{d} (67)	13.2^{b} (58)	3.6^{d} (8)
	0.0009	*0.001*	*0.001*	*0.06*	*0.006*	*1.05*	*0.39*
F-Value	21.8***	6.2.**	33.8***	5.1*	8.3**	7.5**	54.4***

The level of reduction in TSS at the medium density (64%) was not significantly different from the high or low densities (Table 2). Combustion of pond effluent filtrate showed that the effluent contained a higher proportion of inorganic matter (72%) than organic matter (28%). Comparison between the inflow and the control treatments showed that there was no significant settling of total organic or total inorganic matter during the experiment (Table 2). The oysters removed both organic and inorganic material from pond effluent approximately in proportion to the concentrations initially present.

Organisms containing chlorophyll *a* were a minor component of the total organic matter in pond effluent. There was significant settlement of chlorophyll *a* in the controls containing no oysters or only oyster shells (Fig. 4).

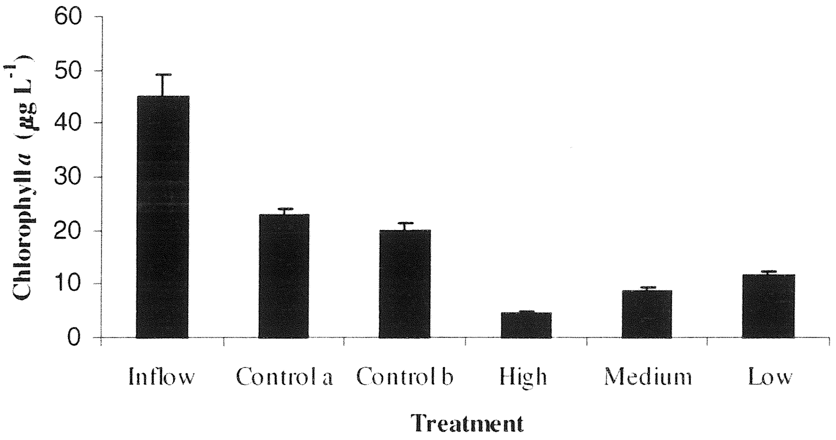


Figure 4. The effects of oyster density on the reduction of chlorophyll *a* in prawn pond effluent. Inflow: untreated effluent, control a: no oysters, control b: oyster shells only.

In addition to settlement in the controls, the concentration of chlorophyll *a* was significantly reduced by the high and medium density oyster treatments but there was no significant difference between the low-density treatment and the controls (Table 2). The combined effects of settlement and oyster filtration reduced the concentration of chlorophyll *a* to 8% of the initial effluent value in the high density and 19% in the medium density of oysters.

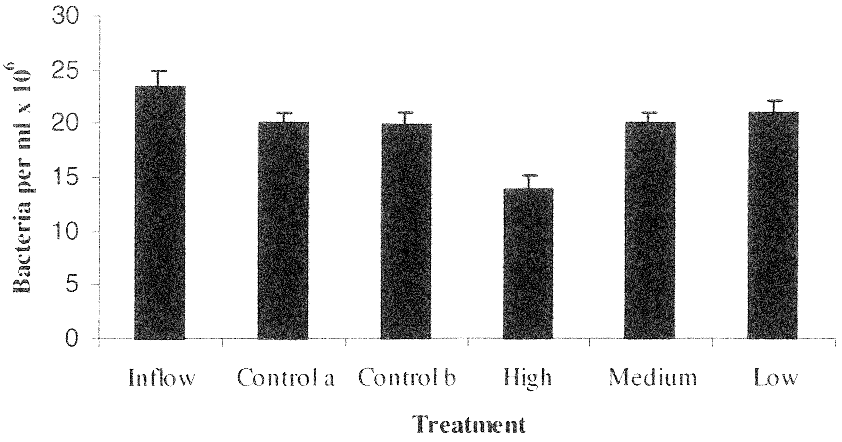


Figure 5. The effects of oyster density on the reduction of total numbers of bacteria in prawn pond effluent. Inflow: untreated effluent, control a: no oysters, control b: oyster shells only.

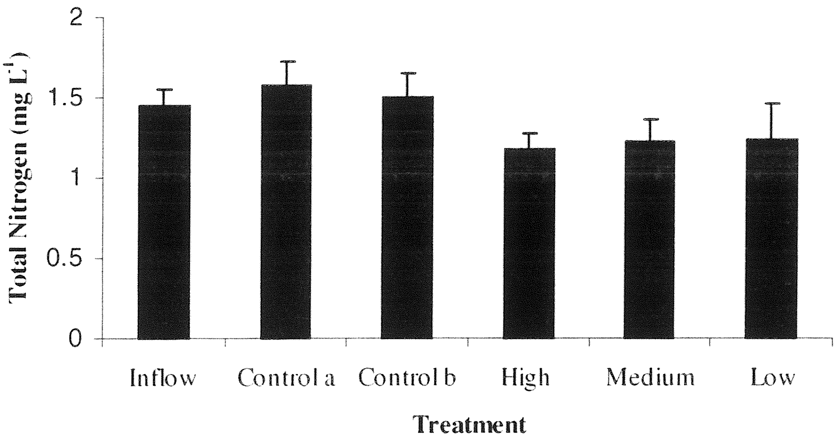


Figure 6. The effects of oyster density on the reduction of total nitrogen in prawn pond effluent. Inflow: untreated effluent, control a: no oysters, control b: oyster shells only.

The medium and low densities of oysters had no significant effects on the concentration total N in the effluent, but the high oyster significantly reduced the total N concentration to 80% of the initial level in the pond effluent. The total P concentration in high and medium density oyster treatments was significantly lower than in the influent water, but the low-density treatment had no significant effect. The high and medium density oyster treatment reduced the effluent total P concentration to 67% and 83% of the initial level respectively.

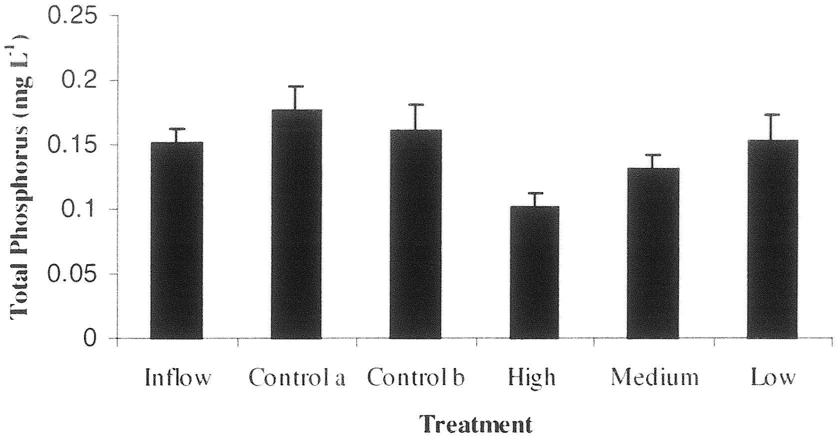


Figure 7. The effects of oyster density on the reduction of total phosphorous in prawn pond effluent. Inflow: untreated effluent, control a: no oysters, control b: oyster shells only.

Discussion

The sediment and nutrient levels in the effluent from the *P. japonicus* prawn farm were comparable to those reported in other studies of prawn farm pond water and effluent (Burford, 1997; Ziemann *et al.*, 1992). The level of chlorophyll *a* in the effluent from the *P. japonicus* ponds was within the range previously recorded for phytoplankton productivity in prawn ponds (Burford, 1997). However, organisms containing chlorophyll *a* were a minor component of the organic matter and approximately 60% of the chlorophyll *a* was removed by settlement alone. Filtration by oysters did remove a significant proportion of the remaining suspended phytoplankton together with other organic matter, including bacteria, the level of reduction depending on the oyster density. The control treatments of no oysters or only oyster shells showed that most of the organic matter remained in suspension during the 2 hour experiment. This organic matter probably consisted of fine detritus derived from prawn feed (Funge Smith, 1996). The high density of oysters effectively halved the total organic load by removing this organic matter from the effluent.

The net effects of oyster filtration on effluent nutrient loads reflect the balance between uptake and excretion. In this study we did not determine the proportion of dissolved or particulate fractions in the total phosphorous or nitrogen load. The net reduction of 23% of the total phosphorus at the highest density of oysters was probably due to the removal of phosphorous bound to organic or inorganic particulates. The net reduction of total nitrogen was less effective, possibly due to removal being balanced by nitrogen excreted by the oysters. The high proportion (72%) of inorganic matter in the effluent from the *P. japonicus* farm is characteristic of effluent from unlined earthen prawn ponds (Ziemann *et al.*, 1992). The lack of any significant settlement during the 2 h period of our experiments indicates that most of the inorganic matter was in the form of very fine particles. Filtration by oysters was effective in removing this suspended sediment, with the high density of oysters approximately halving the effluent load. During filtration oysters sort particles by size and weight; rejected material (pseudofaeces) is accumulated and then expelled through the inhalant opening (Barnes, 1987). Oysters may, therefore, serve a useful role in removing small inorganic particles from effluent. However, high sediment loads can reduce or even arrest oyster filtration (Loosanoff & Tommers, 1948).

Filtration in a flow-through system - effects of oyster size

Materials and Methods

Estimates of the effects of oyster size on filtration of total suspended solids (TSS), total bacteria and chlorophyll *a* were obtained by comparing the results of two separate experiments. Both experiments were done using oysters stocked into plastic (Sabco) trays in 1500 L raceways constructed with concrete blocks (Fig. 8).

The first experiment was done during the mid-phase of prawn farm season when the prawns were approximately 10 g average wet weight. The oysters used were relatively large (55g), these were stocked at 72 oysters per 100 L in three replicate raceways. At 12 hour intervals, for a 72 hour period, 3 replicate 1 litre samples of water were collected from the inflow and outflow point of each of 6 raceways (3 treatment and 3 control). The water samples were returned to the laboratory where analysis was done for bacteria and chlorophyll *a* as detailed previously (see page10).

The second experiment was done in the late phase of the prawn farm season when the prawns were approximately 16 g average wet weight. The oysters used were relatively small (35g) and were stocked at 108 per 100 L in two replicate raceways. At 12 hour intervals, for a 48 hour period, 3 replicate 1 litre samples of water were collected from the inflow and outflow point of each of 4 raceways (2 treatment and 2 control). The control raceways in both experiments contained no oysters, only empty oyster trays. The water samples were returned to the laboratory and analysed for bacteria and chlorophyll *a*.

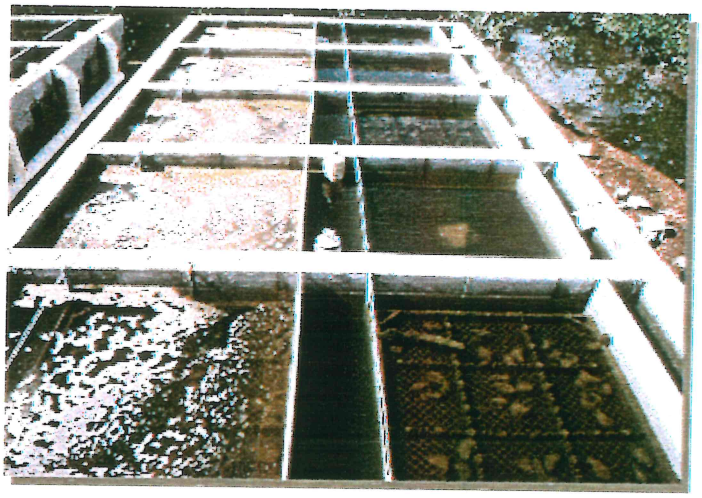


Figure 8. Flow-through raceway tanks (1500 L each) with oysters stocked in plastic (Sabco) trays.

Results

In the late phase of the prawn season, when small (35 g) oysters were used, the effluent TSS and total bacteria concentrations were higher and the chlorophyll *a* concentrations were lower than in the mid phase when large (55 g) oysters were used (Table 3). Comparison of the TSS concentrations before and after filtration showed a 24% decrease for the small oysters and a 52% decrease for the large oysters. Bacterial counts showed that the small oysters reduced the number of bacteria on average by 47% of the initial level while the larger oysters reduced the number by 63% of the initial level. The concentration of chlorophyll *a* was reduced to 32% of the initial level by the small oysters and to 61% by the larger oysters.

	TSS g.L^{-1}	Bact no./ml × 10^{6}	Chl *a* µg.L^{-1}
Small oysters			
Control inflow	0.14	26.5	26
Control outflow	0.126	20.4	20.5
% reduction	10%	23%	21%
oyster inflow	0.14	22.5	26.5
oyster outflow	0.11	11.9	18
% reduction	24%	47%	32%
Large oysters			
Control inflow	0.08	12.1	35.5
Control outflow	0.072	12.2	33.7
% reduction	10%	0%	3%
oyster inflow	0.08	13	26.5
oyster outflow	0.038	4.8	10.3
% reduction	52%	63%	61%

Table 3. Comparison of total suspended solids (TSS), total bacteria and chlorophyll *a* levels in the inflow and outflow of control raceways (no oysters), raceways stocked with small oysters (35 g) and raceways stocked with large oysters (55 g). The experiments with the small oysters were done at the late phase of the prawn farming season and those with the large oysters at the mid-phase of the grow-out season.

Discussion

The results demonstrated that the oysters removed a significant proportion of total suspended solids (TSS), total bacteria and chlorophyll *a* levels from the effluent. However, the reduction in chlorophyll *a* levels were very low compared to those recorded for oysters held in controlled conditions and fed pure algal cultures in the laboratory. For example Gerdes (1983) found that adult *Crassostrea gigas* (0.81 g dry tissue weight) were capable of filtering 191 mg algal dry weight/oyster/day. This is equivalent to 1.9 mg chlorophyll *a*, assuming that chlorophyll *a* comprises approximately 1% of the dry weight of microalgae (Brown, 1997). The results from our experiments gave values for adult *S. commercialis* (2.3 g dry tissue weight) of a removal rate of approximately 0.3 mg chlorophyll *a*/oyster/day. The large oysters were thus apparently removing chlorophyll *a* at approximately 16% the efficiency observed in laboratory studies that used algal densities of 1×10^{5} cells mL^{-1} Similar comparisons can be made for smaller oysters which had an even lower efficiency of approximately 9% of laboratory values. In practical terms, achieving similar levels of reductions of chlorophyll *a* from a one-hectare pond exchanging 2.5 % of water per day would require approximately 60,714 oysters.

Filtration effects on effluent particle size distribution

The effects of oyster filtration on effluent particle removal and particle size distribution were determined using an automated particle counter (coulter counter). The size range of particles examined was from 2.282 µm and 35.2 µm inclusive. The results showed that, within this size range, the majority of the particles in the pond effluent were approximately 3 µm in diameter (Fig. 9).

The results from the particle counter showed that the small oysters had little effect on the removal of particles with only a 3% reduction in the total number of particles. Larger oysters were more effective resulting in a 71% reduction in the total number of particles.

Discussion

The pond effluent used in this study contained a high proportion (72%) of inorganic matter. Although we did not determine the composition of particles it is likely that the majority were inorganic. It is well established that oysters have the capacity to sort particles by composition and size and that inorganic particles are rejected and deposited in pseudofaeces (Barnes, 1987). The results from the particle counts in our study show that oysters, particularly large oysters (55 g), are very effective in filtering small particles (approximately 3 µm) from the water column. We did not measure subsequent deposition or composition of pseudofaeces by the oysters and it would be of interest to do so in future studies.

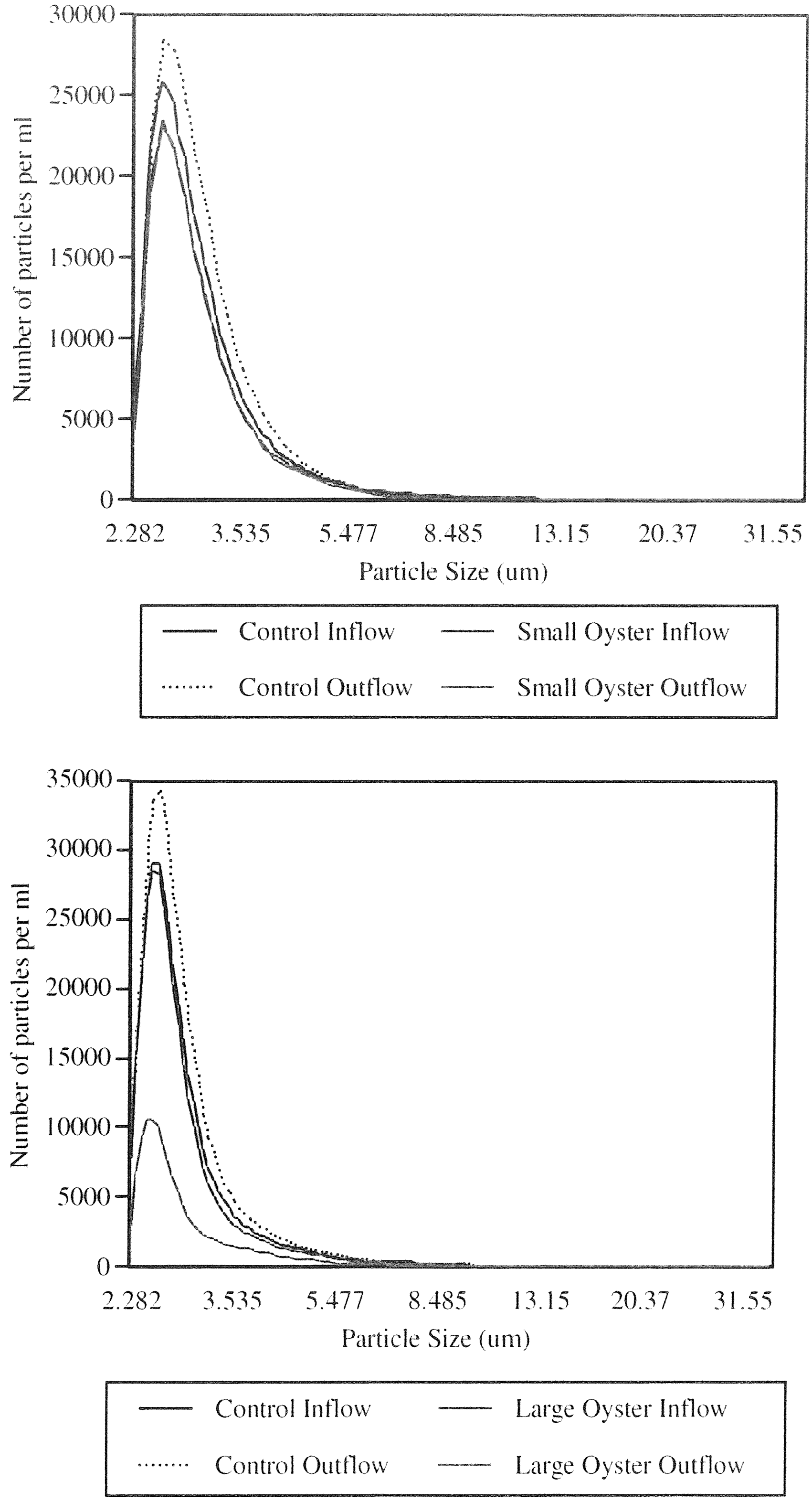


Figure 9. Particle size distribution before and after filtration by small oysters (mean total weight 35 g) and large oysters (mean total weight 55 g).

Filtration in a recirculating system - effects on water quality

Materials and Methods

The recirculating experiment involved sampling at 2 hourly intervals (the time taken for complete water exchange in the raceways) from 9 am to 3 pm on one day to determine the increasing improvement in water quality with successive filtering by the oysters. For the recirculating experiment all twelve raceways were used, all with the smaller 35g oysters. Three were controls with no oysters. Of the other nine raceways, six were stocked at 108 per 100L and three at 216 per 100L. After the water passed through each raceway, it flowed into a separate recirculating tank from where it was once again pumped back into each raceway (Fig. 10).

Results

Total bacteria were reduced to 54% of the initial concentration in the first circuit of the effluent through the raceways (Fig. 11). Subsequent filtration resulted in further reduction to 12% after three circuits. Progressive reduction in concentration was also achieved for total suspended solids and chlorophyll *a* (Figs 12 & 13).

For total suspended solids there was no significant reduction in the first circuit. Subsequent circuits progressively reduced the TSS concentrations to 63%, 32% and finally 20% of the initial level (Fig. 12).

For chlorophyll *a* the results were less consistent. After the first circuit there was no significant variation between the levels of chlorophyll *a* in the inlet and outlet of the recirculation system. One hour later, after a second complete circuit through the recirculating system, the level of chlorophyll *a* was reduced to approximately 20% of the initial level. After one more circuit there was a further reduction to 4% of the initial level but in the final circuit the level increased to 20% of the initial value.

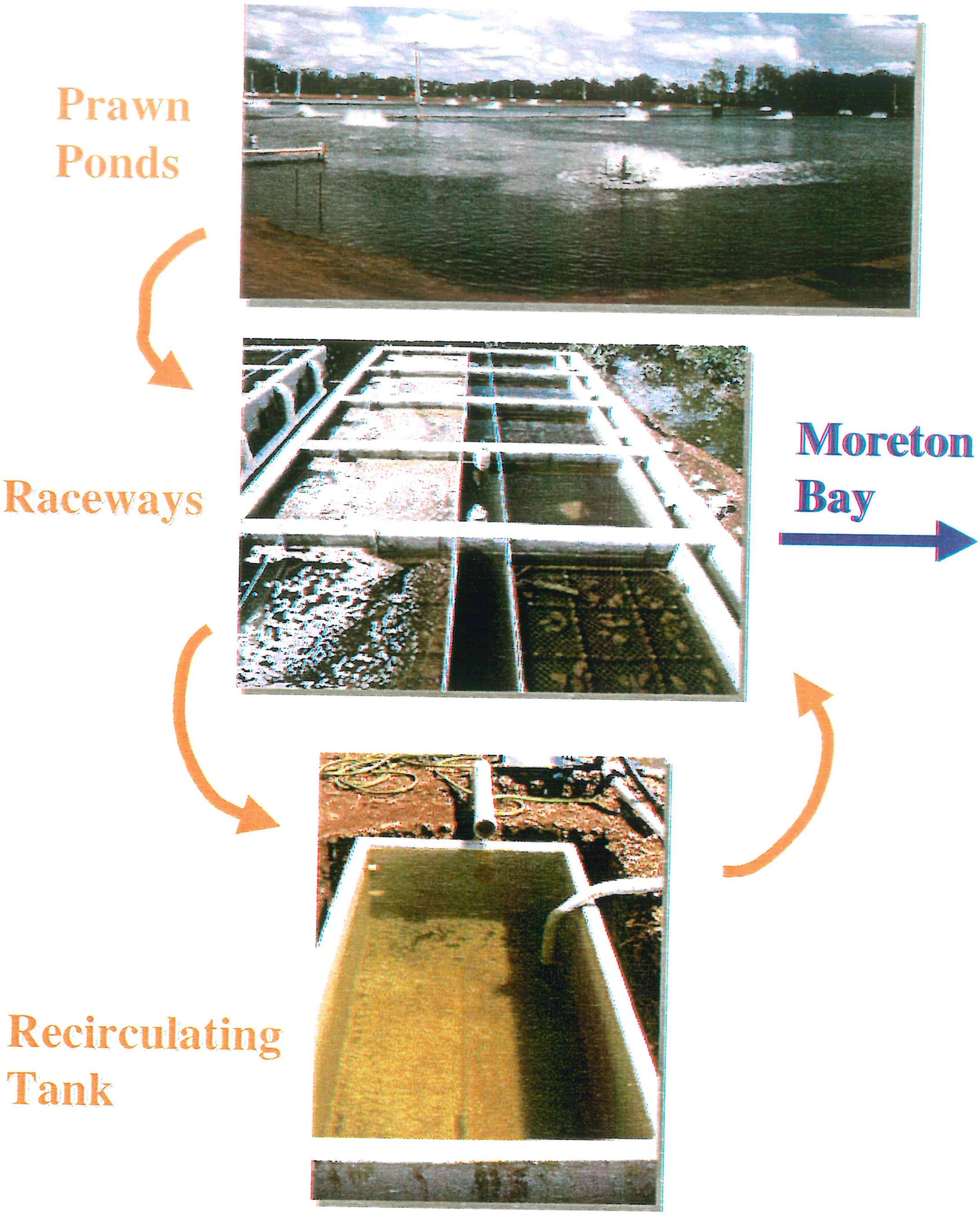


Figure 10. Schematic representation of the system used to determine the effects of a recirculation system on the efficiency of oyster filtration of prawn pond effluent.

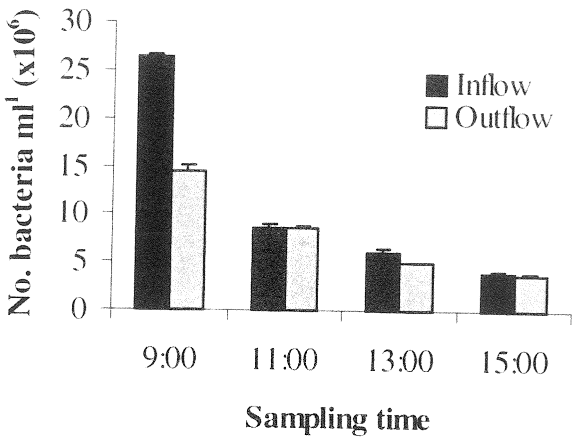


Figure 11. Variation in the total number of bacteria in water samples collected at 2 hourly intervals from the recirculating system inflow and outflow.

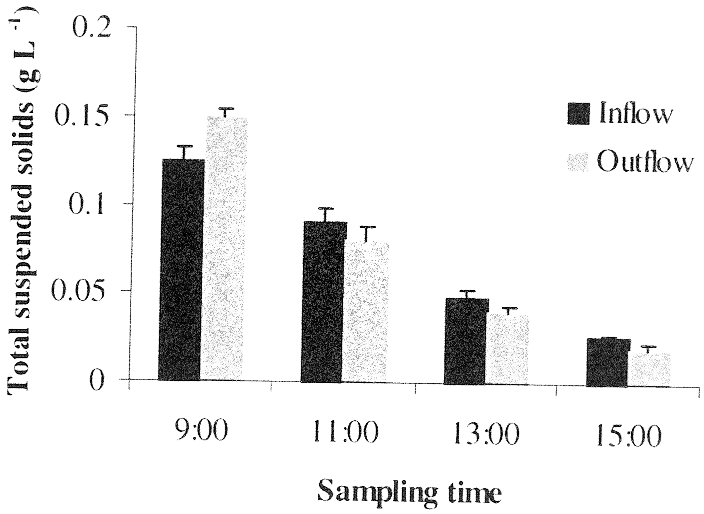


Figure 12. Variation in total suspended solids in water samples collected at 2 hourly intervals from the recirculating system inflow and outflow.

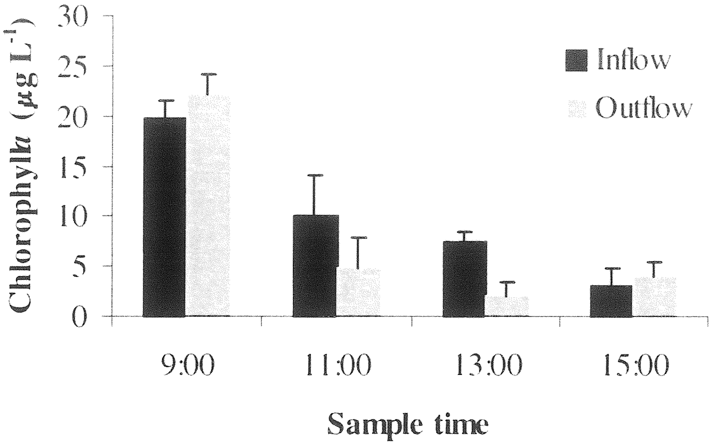


Figure 13. Variation in chlorophyll *a* concentration in water samples collected at 2 hourly intervals from the recirculating system inflow and outflow.

Discussion

The results demonstrated that a system in which pond effluent is recirculated through raceways containing oysters progressively improves the effluent water with each circuit of the system. We did not attempt to distinguish between the effects of the raceways alone and the effects of the oysters. The progressive reduction numbers of bacteria and levels of chlorophyll *a* indicate that oysters are an effective component of the recirculation system. However, further studies are needed to clearly distinguish between the effects of the raceways alone and the effects of the oysters

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The growth and condition of oysters grown in pond effluent

Introduction

The prawn pond effluent examined in this study contained elevated concentrations of bacteria and chlorophyll *a* and suspended sediment compared to those in the receiving waters in Moreton Bay (Dennison *et al.*, 1993). Elevated concentrations of bacteria and chlorophyll *a* in pond effluent are a potential source of food for oysters. Conversely, elevated concentrations of suspended solids can reduce the feeding ability of the oysters. For example, Loosanoff and Tommers (1948) found the concentration of suspended silt had a major effect on the pumping rate of oysters and that, in high concentrations of silt, oysters may cease pumping entirely. In this component of the study we compared the increase in growth (total gain in dry weight of flesh) of oysters grown in pond effluent compared with those grown at a commercial oyster lease site in Moreton Bay and at a third site located at Raby Bay Marina (Fig 1).

Materials and Methods

Oysters collected from the oyster lease (Fig. 1) were initially starved for two weeks in sand filtered seawater at the Cleveland Marine Laboratories. The oysters were then tagged (with plastic "dyno-tape" attached to the shell with epoxy glue), measured (length, width and depth) and weighed prior to deployment at three locations. The three locations were the effluent canal at Moreton Bay Prawn Farm, a commercial oyster lease in Moreton Bay and Raby Bay Marina (Fig. 1). After a period of 6 weeks, the oysters were collected reweighed and the total weight and flesh weight increases determined. In the experimental design there were three replicates for each site. Each replicate consisted of a mesh bag containing 21 oysters.

Results

The level of chlorophyll *a* in the pond effluent at Moreton Bay Prawn Farm was more than 10 times greater than at Raby Bay or at the natural oyster lease site in Moreton Bay (Fig. 14).

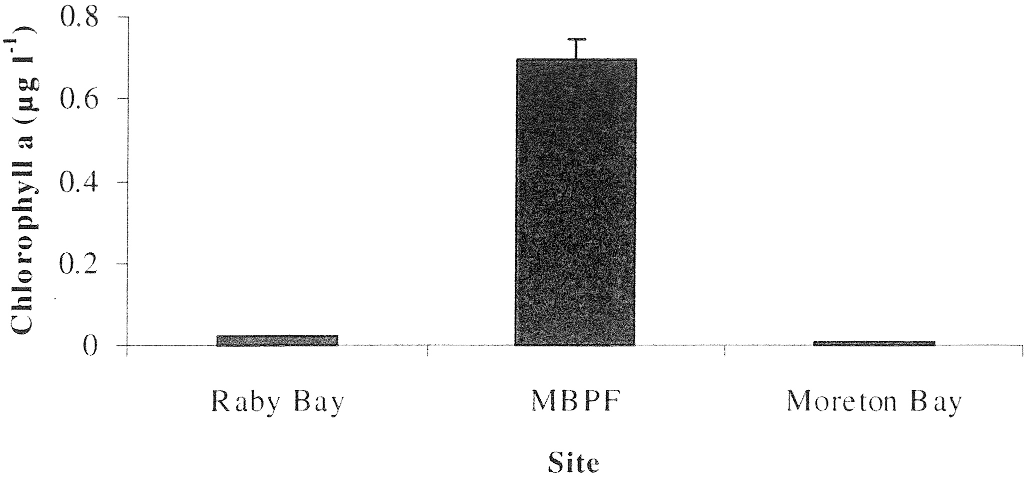

Figure 14. Chlorophyll *a* concentration at the various sites used for growing oysters

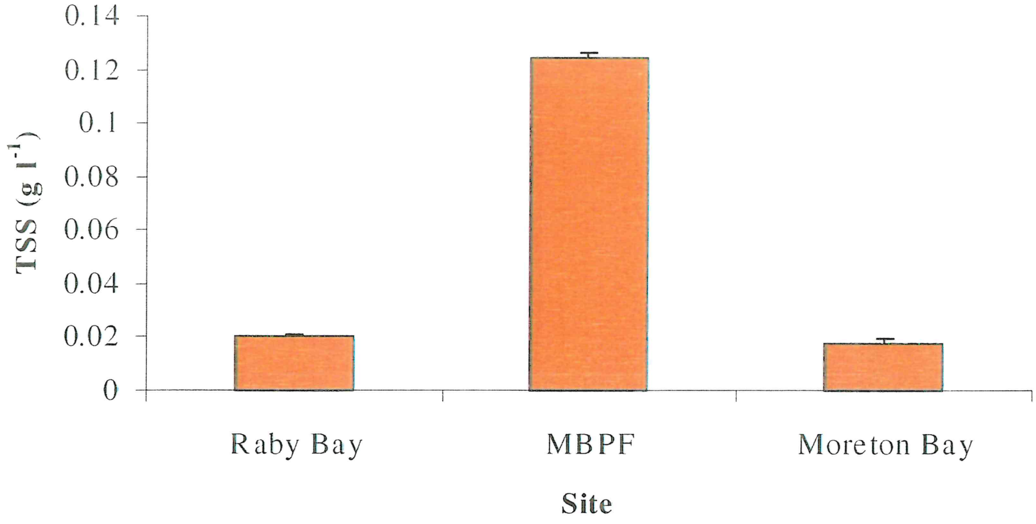

Figure 15. Total suspended solids concentration at the various sites used for oyster growth analysis

The level of total suspended solids was six times greater in the effluent channel at Moreton Bay Prawn Farm than at Raby Bay or at the natural oyster lease site in Moreton Bay (Fig. 15).

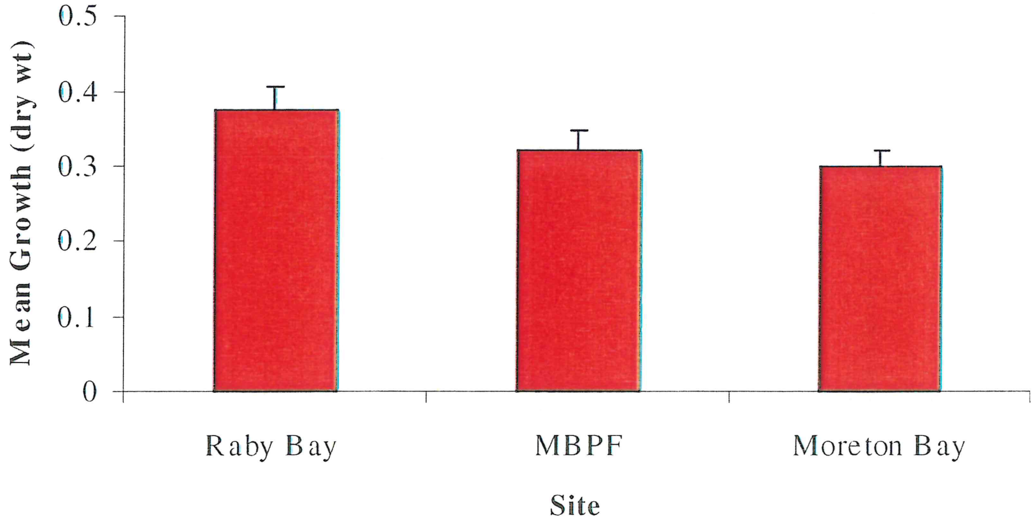

Figure 16. Mean oyster growth at the selected sites over the 6 week period.

Despite the high concentrations of chlorophyll *a* in the effluent at Moreton Bay Prawn Farm the oysters in the effluent channel did not gain significantly more weight than those at the other two sites (Fig. 16).

Discussion

Elevated levels of chlorophyll *a* in the pond effluent were indicative of increased phytoplankton biomass in the production ponds (Burford, 1997). However, the results demonstrated that the oysters were unable to take advantage of the phytoplankton as a source of food. One possible explanation for the inability of the oysters to utilise the higher phytoplankton biomass in the effluent channel is that elevated levels of suspended solids (silt) in the effluent reduced the pumping rate of the oysters. Previous studies have shown that the concentration of suspended silt has a major effect on the pumping rate of oysters and that, in high concentrations of silt, oysters may cease pumping entirely (Loosanoff & Tommers, 1948). Further research is required to determine if reducing the suspended solids in the effluent by sedimentation, prior to filtration by oysters will permit improved filtration and assimilation of the phytoplankton.

BENEFITS

The principal benefit of this research is in providing quantitative information about the effectiveness of oysters in improving prawn pond effluent water quality prior to discharge or recirculation. Prawn farmers and environmental managers can now use this information to more effectively assess the options for achieving cost-effective pond effluent management. Our results indicate that oysters could be effectively used in an integrated effluent treatment system that permits sedimentation of suspended solids prior to oyster filtration. Such systems are currently being developed in Australia and elsewhere (Preston *et al.*, 1997, Jones & Preston, 1999, Chien & Liao, 1995; Jacob *et al.*, 1993). The introduction of recirculating systems that include oyster filtration as part of the pond effluent treatment system offers potential savings in pumping costs, and the ability for prawn farmers to operate for substantial periods of time in isolation from intake or receiving waters. The potential for oyster farmers to enhance growth rates and oyster condition using phytoplankton from prawn ponds is yet to be determined. As outlined above, our results indicate that there is potential to increase the growth of oysters by using prawn pond effluent as a source of nutrients, providing that silt load is reduced by sedimentation prior to oyster filtration. Providing that the silt load was successfully reduced to the level that we have achieved in this study (<0.05 gL^{-1}) it would be possible to remove 1.68×10^{16} algal cells/week (see Wang, 1990) from the effluent of a half-acre prawn pond using approximately 2,500 oysters, with mean total weight 35 grams.

FURTHER DEVELOPMENT

This project was a two-year study. However, further development of the project was achieved through the successful application for a PhD scholarship at Queensland University. The scholarship was awarded to Adrian Jones who was employed as contract graduate biologist on this project. Adrian's PhD project examined techniques to prevent fouling of oysters, enhancing oyster filtering efficiency and the incorporation of oysters into an integrated effluent management and treatment system. Adrian was awarded his PhD in April 1999 and his research has added considerable value to the research initiated and achieved in this project. As summarised below, we anticipate that the results of this research will be incorporated into the design and operation of the integrated effluent management and treatment systems that are now under development in Australia and elsewhere.

CONCLUSION

This study was initiated by prawn farmers and oyster growers in Moreton Bay, Queensland. The primary objective was to explore the potential of growing oysters in the discharge canals of prawn farms. Growing oysters in pond effluent was seen to have potential benefits for both industries. Prawn farmers were interested in the potential of using oysters to filter waste nutrients from the prawn pond effluent prior to re-circulation or discharge. The oyster farmers were interested in the potential of enhancing the growth and condition of oysters using the high phytoplankton biomass in prawn pond effluent.

Prior to the study, little was known about the effectiveness of using oysters to improve the water quality of prawn pond effluent or the effects of the effluent on the survival and growth of oysters. The results of this study have clearly demonstrated that oysters can significantly reduce the bacteria, phytoplankton, nitrogen and phosphorus (particulate and dissolved) in pond effluent (Jones & Preston, 1999). The effectiveness with which oysters can remove pond wastes can be enhanced using a recirculation system. However, the results of the study also indicated that the high concentration of suspended inorganic particles (fine silt) in pond effluent inhibits the filtration rates and growth of oysters. Furthermore, a related project (FRDC 95/162 - *Prawn farm effluent: composition, origin and treatment*), has demonstrated that untreated pond effluent is highly variable in composition.

The use of oysters may be most effective if incorporated into integrated effluent management and treatment systems. These systems would need to promote a reduction in suspended inorganic particles by sedimentation prior to oyster filtration. The processes within the systems would also need to be well enough understood to permit sufficient water quality control for the conversion of waste nutrients to cash crops. The design and operation of such systems are at an early stage of development in Australia (Preston *et al.*, 1997, Jones & Preston, 1999) and elsewhere (Chien & Liao, 1995; Jacob *et al.*, 1993; Franco-Nava *et al.*, 1999, Teichert-Coddington *et al.*, 1999). In Australia, prawn farms in the Logan River region of S.E. Queensland lead the development of integrated prawn pond effluent treatment systems (see FRDC 95/162). The systems currently being developed use treatment ponds to promote settlement of suspended inorganic and organic matter, filtration of suspended matter by naturally occurring filter feeders (eg barnacles and tube worms), and uptake of dissolved nutrients by phytoplankton and other marine flora including filamentous and benthic algae.

The current reliance on natural biota reflects the fact that these systems are at an early stage of development. Although these systems can be effective in effluent nutrient reduction (see FRDC 95/162), the biological and chemical processes within the treatment ponds are not well understood. Once these systems are better understood, it is likely that prawn farm managers will be able to convert a proportion of effluent nutrients to cash crops such as oysters and macroalgae (Jones *et al.*, 1999a). The results of our study indicate that, in a well-designed treatment system, Sydney rock oysters could provide an effective means of improving effluent water quality and recapturing otherwise wasted nutrients.

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Communication of results

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APPENDIX 1. INTELLECTUAL PROPERTY AND VALUABLE INFORMATION

The information contained in this report is intended for unrestricted use by industry and research.

APPENDIX 2. STAFF

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