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(Accepted 23 September 2001)

Journal of TFRI
TAIWAN
1993
Fisheries Research

Development of an Outdoor Super-intensive Recirculation Eel Culture System

Abstract

A Danish type indoor super-intensive recirculation system was built outdoors and modified in order to significantly reduce the cost of the system, especially the cost of the greenhouse. A sun net sheltered the whole system. Submerged biofilter, trickling biofilter, and drumfilter were installed the same as in the indoor system. However, modified paddlewheel aerators replaced the oxygenation equipment. Illumination, chiller and UV sterilization equipment were removed. A rearing experiment of the European eel *Anguilla anguilla* was carried out from Jan. 6 to Oct. 6, 1999. In the system, 430.71 kg and 864.49 kg of eels of average weight 128 g per eel was stocked in two 5 m x5 m x1.8 m ponds, respectively.

At harvest on October 6, 1999, a total of 2,899.23 kg was recovered. The total weight increment was 1,604.03 kg, which is 13 times more than the production of a conventional outdoor system in the same area. The water usage was 1.34 metric ton per kg of eel produced, higher than the indoor system (0.7 metric tons/kg), but far less than the conventional outdoor eel ponds (20-30 metric tons/kg). Daily recording of water temperature, air temperature, DO, pH, transparency, death rate and feeding rate was carried out. A computer based water quality monitoring system was used to record continuously water and air temperature, and DO. It was found that the environment was no less stable than the indoor system. With similar biofilter capacity, the NH_4^+ level was kept at very low level. The performance of the system in terms of eel production was as good as the indoor system, while the capital cost of the outdoor system is about two-thirds that of the indoor system.

Key words: Eel-culture, Recirculation, Super-intensive, Outdoor

Freshwater eels *Anguilla spp.* are the most important freshwater aquaculture species in Taiwan in terms of commercial value. Most of eel culture, however, is of the conventional still-water pond culture. Accordingly, problems such as overuse of water and land resources, and managerial difficulties have occurred. Also, the production and value have declined continuously since 1994 (Fig. 1) because of the shortage of elvers of the Japanese eel *Anguilla japonica* and strong competition from mainland China which has more abundant water resources, lower land price and labor cost. The culture of exotic species as alternatives, especially the European eel *Anguilla anguilla* was difficult in conventional still-water pond system. Virtually all of the previous trials for the European eel culture in Taiwan failed. Table 1 compared the characteristics of the Japanese eel and European eel for aquaculture.

Shyu, C. Z. and I C. Liao (2001) Development of an outdoor super-intensive recirculation eel culture system. J. Taiwan Fish. Res., **9**(1&2): 209-220.

A super-intensive recirculating eel culture technology was developed in the last decade in Taiwan to overcome the above-mentioned problems and develop a sustainable industry. The Taiwan Fisheries Research Institute (TFRI) successfully reared two batches of the European eel in 1993-1994 using a super-intensive recirculation system(1). The utilization of the system not only saved water and land resources, but also provided suitable environment for the European eel to grow. However, owing to high capital cost of the culture system and low market price of the eel product, the extension of the technologies is currently limited to 7 farms in Taiwan.

This study aimed at developing an eel culture system with lowered capital cost and, hence, solving the constraints mentioned above without sacrificing the performances and advantages of a super-intensive recirculation system. Strategies for the system development are as follows:

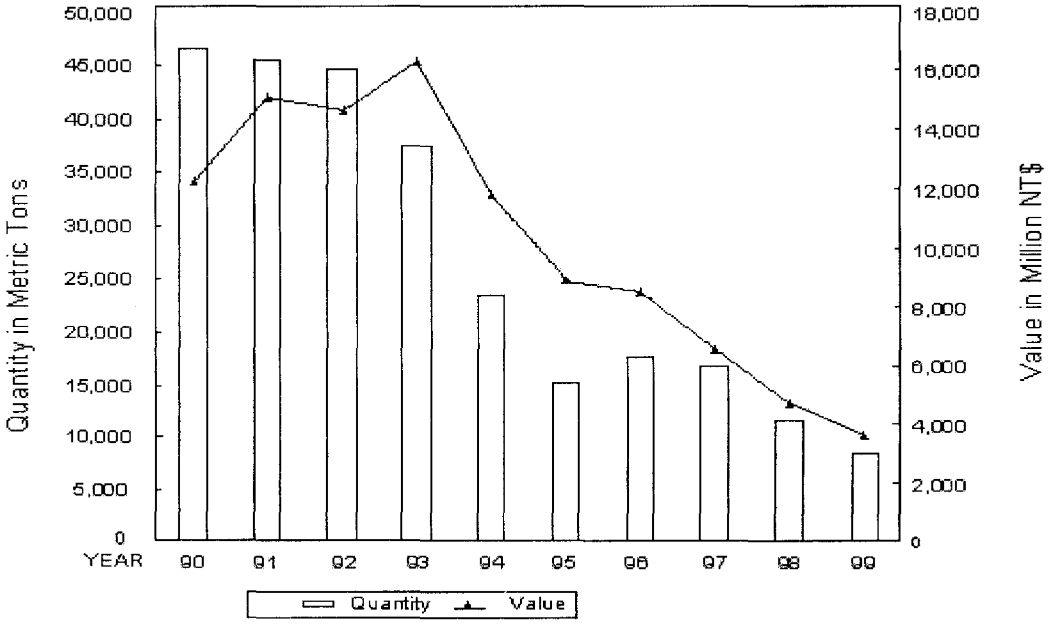

Fig. 1. Quantity and value of eel product export of Taiwan.

Table 1. Comparison of *Anguilla anguilla* and *Anguilla japonica* for aquaculture.

	Anguilla anguilla	***Anguilla japonica***
Price of elver	Low	5-10 times higher
Optimal T(℃)	22-25	25-28
Dactylogyrosis	Vulnerable	Resistant
Growth near marketable size	Slow	Fair

1. Move systems outdoor to save housing cost.
2. Simplify O_2 supply and DO control by utilizing a modified paddlewheel aerator.
3. Remove facilities such as illumination, ventilation, UV sterilization, buffer dispenser and chiller, etc.

The purpose of this study is to design and establish the outdoor recirculation system and to test the performance of the system in terms of feasible stocking densities, water consumption, water qualities variation, survival rate and growth rate of the cultured eels, and conduct economic comparison of the indoor/outdoor system.

Materials and Methods

The outdoor super-intensive recirculation eel culture system used in this experiment is shown schematically in Fig. 2. The arrows denote water flow direction of the pipelines, and the "P" letters denote pumps of different capacity. Two concrete round-corner square ponds of 5 m x 5 m in size and 1.8 m deep were used for culturing eel. The total water volume of the system including biofilters is 105 m^3. Shelter net was installed above the ponds to reduce sunlight.

The rearing experiment of the European eel was started from January 6 and continued to October 6 and divided into three culture periods. In the first period from January 6 to April 1, the initial stocking weight of pond 1 was 430.71 kg in 25 m^2, while that of pond 2 was 864.49 kg, i. e. the stocking density of pond 2 was twice that of pond 1 (Table 2). In the second period from April 1 to July 5, the eels of these two ponds were pooled and graded into larger and smaller group, each

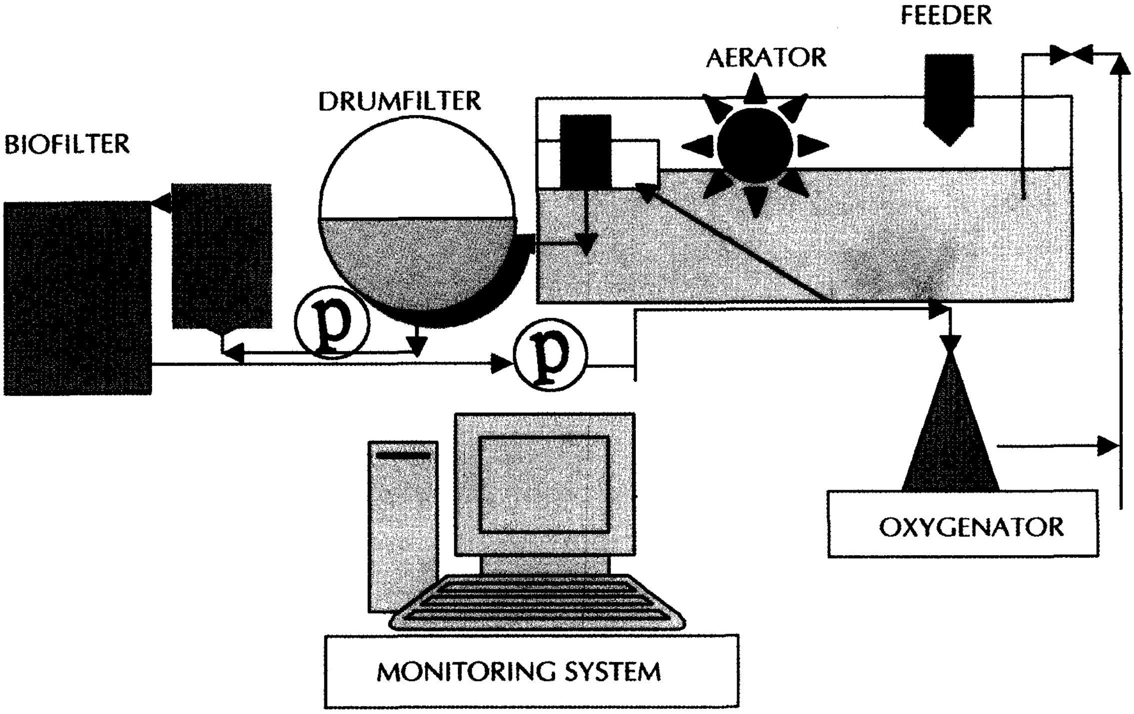

Fig. 2. Schematic diagram of the outdoor super-intensive recirculation eel culture system.

group with eels of about the same weight, and stocked in pond 1 and pond 2 respectively (Table 3). In the third period from July 5 to October 6, the eels of these two ponds were further pooled and graded into larger and smaller group as before and stocked in pond 1 and pond 2 respectively (Table 4). On the last day of every period, the eels were harvested and weighed, and individuals were sampled for investigating size distribution and averages.

Table 2. Eel culture results of different stoking densities in the period of Jan. 7- April 1.

	Pond 1	*Pond 2*
Initial total weight (kg)	430.71	864.49
Initial average weight (g/eel)	123.13	123.13
Final total weight (kg)	564.80	1198.73
Final average weight (eel)	162.86	171.59
Number of death recovered (eel)	30	35
Total weight increment (kg)	134.09	334.24
Feeds used (kg)	452.00	519.60

Table 3. Eel culture results of different size groups in the period of April 1-July 5.

	Pond 1	*Pond 2*
Initial total weight (kg)	813.71	949.82
Initial average weight (g/eel)	261.56	136.50
Final total weight (kg)	1160.3	1231.09
Final average weight (eel)	355.6	181.36
Number of death recovered (eel)	11	28
Total weight increment (kg)	346.59	281.27
Feeds used (kg)	649.5	671.5

Table 4. Eel culture results of different size groups in the period of Jul. 5-Oct. 6.

	Pond 1	*Pond 2*
Initial weight (kg)	1338.11	1047.55
Average weight (g/eel)	372.44	162.05
Final weight (kg)	1742.4	1156.83
Average weight (g/eel)	497.5	209.17
Number of death (eel)	5	9
Weight increment (kg)	404.29	109.28
Feeds used (kg)	765.1	619.1

The environment monitoring, including pond water and air above, was carried out.

Temperature, pH, DO, transparency, mortality and feeding ration were recorded daily. A PC-based monitoring of water temperature (℃) of pond 1 & 2, air temperature (℃) at sheltered and unsheltered location above ponds and DO of pond water were carried out and recorded every 10 minutes. NH_4^+, NO_2^-, and NO_3^- concentrations were measured every week to monitor the performance of the biofilters.

Results

I. Growth of eels in the rearing experiment

In the first period of the rearing experiment, it was found that mortalities of death in both ponds were very low (Table 2). Final average weight were greater for eels cultured in pond 2 than in pond 1, while feed conversion rate in pond 2 (FCR=1.55) was much better than that in pond 1 (FCR=3.37) although stocking density of pond 2 was twice that of pond 1 in terms of weight or individual number per unit water volume.

In the second period, although the initial total weight in pond 2 was only 11% greater than that of pond 1 (Table 3), the stocking density in pond 2 was 2.24 times than in pond 1 in terms of individual numbers per unit water volume because the initial average weight was greater in pond 2. The total increment was greater in pond 1 than pond 2 while feed conversion rate in pond 1 (FCR=1.87) was better than in pond 2 (FCR= 2.39). Mortalities of death in both ponds were also very low.

In the third period, the stocking density in pond 2 was also much higher (1.8 times) than that in pond 1 in terms of individual number per unit water volume. The total increment was greater in pond 1 than in pond 2, while feed conversion rate in pond 1 (FCR=1.89) was much better than pond 2 (FCR=5.67). Mortalities of death in both ponds were also very low.

Table 5 lists the calculated specific growth rate and FCR of the three periods in both ponds where pond 2 was stocked about twice in density than pond 1 in terms of individual numbers per unit water volume. The only difference is that eels of similar size were stocked initially in period 1 while eels of much larger size were stocked in pond 1 than in pond 2 in periods 2 and 3 (Tables 2, 3, 4). It was found that growth rate decreased from period 1 to 3 in both ponds while FCR was better for pond 1 in the periods 2 and 3, but worse in the first period. The size distribution of harvested eels at the final date of culturing experiment (Oct. 6) (Fig. 3) showed that the peak of individual numbers was 150-200 g/eel in pond 1, and in pond 2 the peak was 500 g/piece. The total of two distributions of each size showed peaks from 150 to 500 g/eel, which is equivalent to 2-6 eels/kg, the right size for most of the world markets.

Table 5. Growth rate (R) and FCR of 3 periods of eel culture experiment, where r=(LN Wt-LN Wo)*100/t; FCR=Feeds/(Wt-Wo); Wo and Wt are initial and final total weight of each period, respectively.

R (FCR)	*Pond 1*	*Pond 2*
Period 1(Jan.7-Apr.1)	45% (3.37)	45% (1.55)
Period 2(Apr.1-Jul.5)	0.32% (1.87)	30% (2.39)
Period 3(Jul.5-Oct.6)	31% (1.89)	27% (5.67)

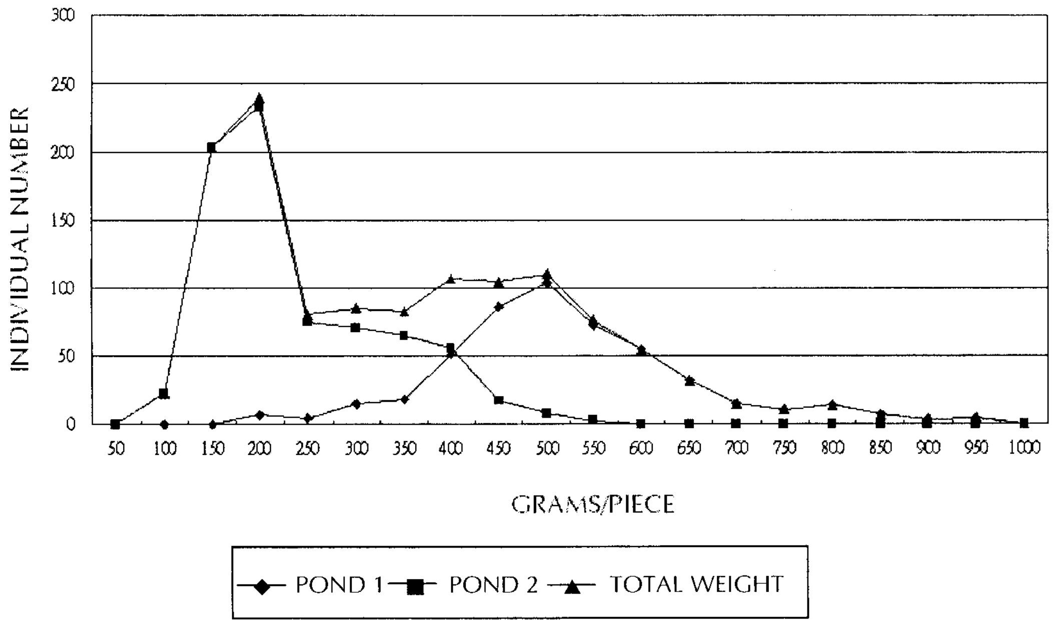

Fig. 3. Size distribution of harvested eels at the final date of the cultur experiment.

The major performance items of different eel culture sytems, i.e. stocking density, water consumption and feed conversion rate are compared in Table 6. The stocking density of the outdoor super-intensive system, calculated from the final total weight of pond 1, was 70 kg eel/ton water, which is of the same level as in Danish type indoor super-intensive system (80 kg eel/ton water,(1) and much better than the conventional outdoor intensive culture (2 kg eel/ton water for soft/soil bottom pond and 3 kg eel/ton water for hard/concrete bottom pond). Water consumption in terms of metric tons per kg of eel production was 1.34 in average in the whole period of the present study, which is twice that of the indoor super-intensive system (0.7 tons(2)), but far less than that of the outdoor conventional culture (20-30 tons for hard/concrete pond; and 10 tons for soft/soil bottom pond(1)). Feed conversion rate of present study was 1.55-3.37 (Table 5), which is about the same level as indoor super-intensive culture (1.70 - 2.03)(3) of the same batch of eel and using the same kind of pellet feed as present study, and better than outdoor conventional culture(4-6) using dough feed.

Table 6. Comparison of functions of different aquacultural systems.

Aquacultural Systems	*Density (Kg eel/ton water)*	*Water used (ton /Kg eel)*	*Feed conversion rate*
Indoor super-intensive	80	0.7	1.70-2.03*
Outdoor conventional	2-3	20-30	4-6**
Outdoor supe-rintensive	70	1.34	1.55-3.37*

*:Pellet feed; **:Dough feed

II. Environment of the system during the rearing experiment.

Table 7 shows the average and standard deviation of several water quality items, i.e. water temperature, DO, transparency, pH value, and feed ration during the whole rearing experiment from Jan. 7 to Oct. 6. The average of the water temperature was 23.1 ℃ at 9 AM and 23.8 ℃ at 3 PM, which is in the range of the optimal culture temperature (Table 1). From Fig. 4 the variation of water temperature showed that the lowest temperature was 12.5 ℃ in February (day 30 th) and the highest was 29.5℃ in August (day 190 th).

Table 7. Averages (*) and standard deviations (**) of water quality and feed ration of pond 1 and pond 2 of the outdoor systems in 9 AM and 3 PM. from Jan. 7 to Oct. 6.

	Pond 1 (9 AM)	*Pond 1 (3 PM)*	*Pond 2 (9 AM)*	*Pond 2 (3 PM)*
Water Temperature(℃)	23.1*±4.0**	23.8±4.2	23.1±4.0	23.8±4.2
Dissolve Oxygen(ppm)	6.6±1.4	6.7±1.2	6.7±1.4	6.7±1.2
Transparency(cm)	97±31	97±31	98±31	98±31
PH value	7.19±0.54	7.21±0.54	7.15±0.59	7.17±0.54
Feed ration(Kg)	4.1±1.85	4.2±1.72	4.5±1.54	4.8±1.19

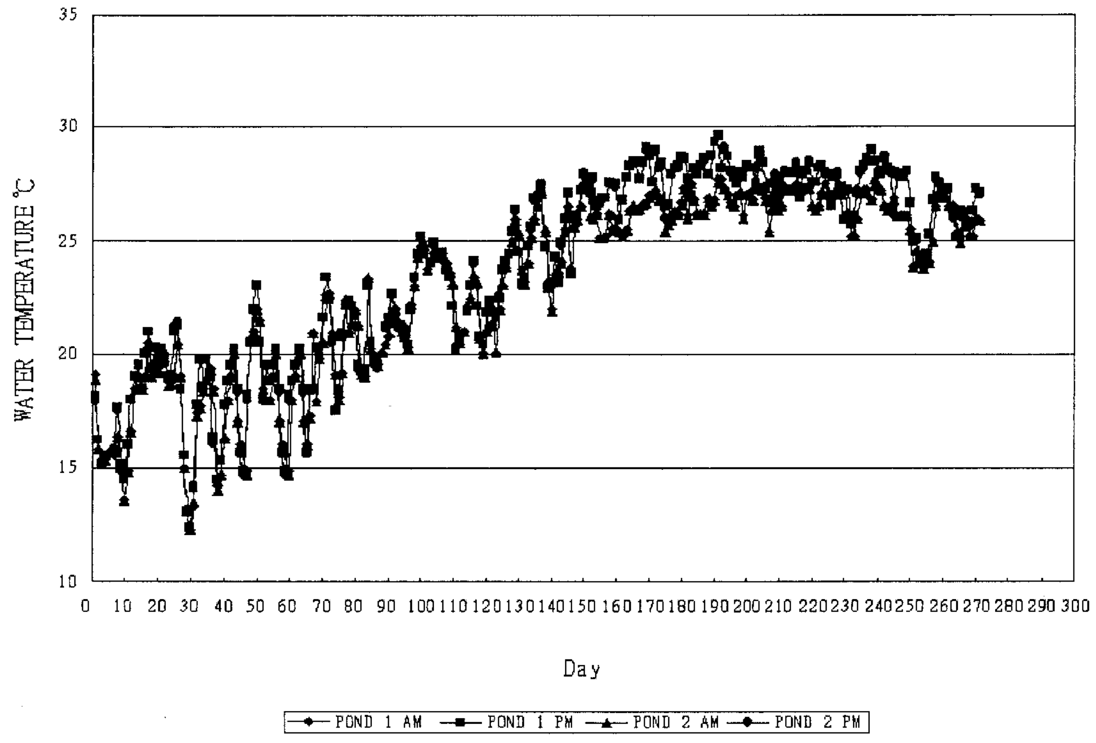

Fig. 4. Variation of water temperature in the outdoor super-intensive recirculation eel culture system.

Fig. 5 shows the variation of concentration of NH$_4^+$, NO $_2^-$ and NO$_3^-$ .NH$_4^+$ concentration was kept at a low level, below 4 ppm. NO$_2^-$ concentration was also low in most of the rearing period and increased significantly in the later period to 13 ppm. NO$_3^-$ concentration fluctuated greatly owing to biofilter function and exchange of water. pH values (Table 7) were stable without adding buffer. It is possible that the pH level balance was balanced by nitrification of biofilter and photosynthesis of algae with adjustment of water exchange. Transparency varied periodically by exchange of water and increase of suspensded solids. Feeding ration was consistent owing to good appetite and health of cultured eels. DO level was kept at around 6.7 ppm (Table 7).

Fig. 6 shows fluctuation of DO of outdoor and indoor system. The typical DO of the outdoor system in this study showed stable level near saturation with slumps coinciding with the 2 meal times. In contrast, the typical DO variation in indoor system showed supersaturation in the resting time at night(4). At daytime, the slumps of the DO level coincided with the 4 meals. However, the prolonged recovery time resulted in the DO level declining to less than 6 ppm, which is the low limit of optimal DO level for eels.

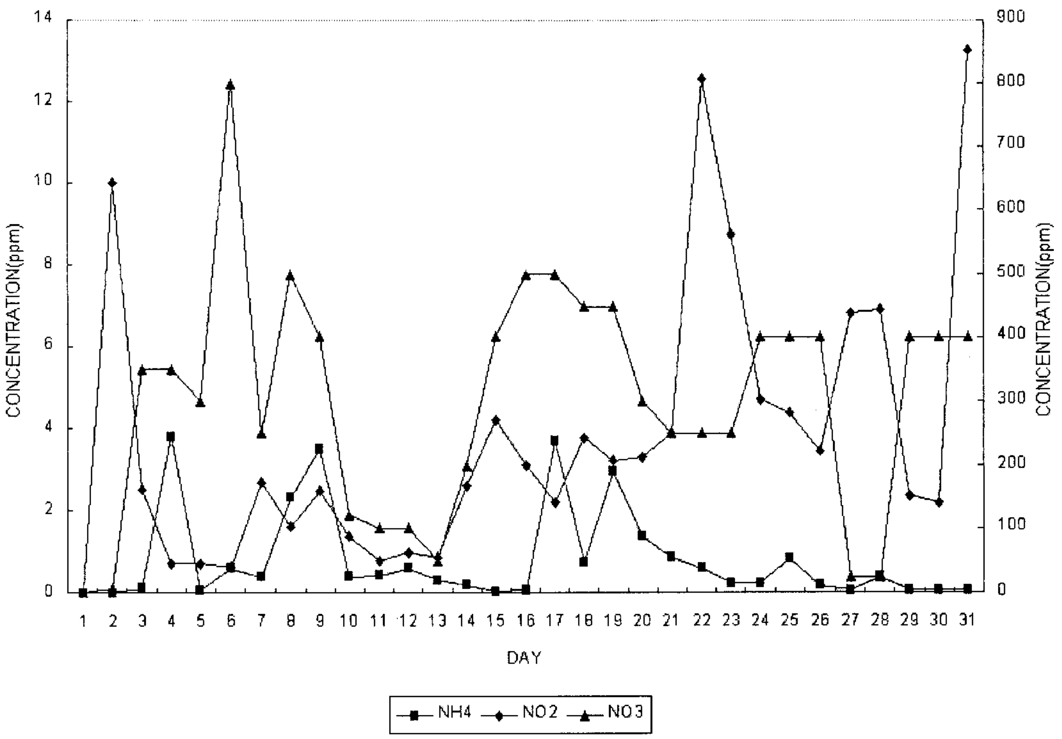

Fig. 5. Variation of concentration of NH$_4^+$ 、NO$_2^-$ and NO$_3^-$ in the outdoor super-intensive recirculation eel culture system.

Discussion

I. Performance of the recirculating fish production system.

The sum of final weights in both pond 1 and pond 2 of whole period was 2,899.23 Kg in 50 m^2 area, and the sum of total weight increments (production) was 1604.03 Kg in the whole 9 months period or 427,741.32 Kg/ha/year calculated on the basis of average growth rate. Fig. 7 shows the reverse relationship of specific growth rate and average initial stocking size. It was found that the ranges of the specific growth rate of the present study (Table 5) was about the same level as that of the super-intensive recirculation systems of private farms when the average initial stocking sizes were similar (about 100 g/eel). If the initial stocking size were lowered in this study, the outdoor system might have higher growth rate and, hence, higher productivity.

Judging from the similar specific growth rate (Fig. 7) and stocking density of indoor system(3) and outdoor system (present study) of the same growth stages, the productivity of the two systems is also similar. Provenzano et al.(5) developed a recirculating fish production system and succeeded in producing 121 Kg under a surface area of 10.7 m^2. This production is equivalent to approximately 121,000 Kg/ha/yr. Judging from the same criteria in an aeration type recirculating fish production system, the performance of the system in the present study is 3 times better. On the other hand, compared with the annual production of the conventional outdoor eel culture system (20,000 - 30,000 kg/ha), the present system is about 14 - 21 times higher in productivity.

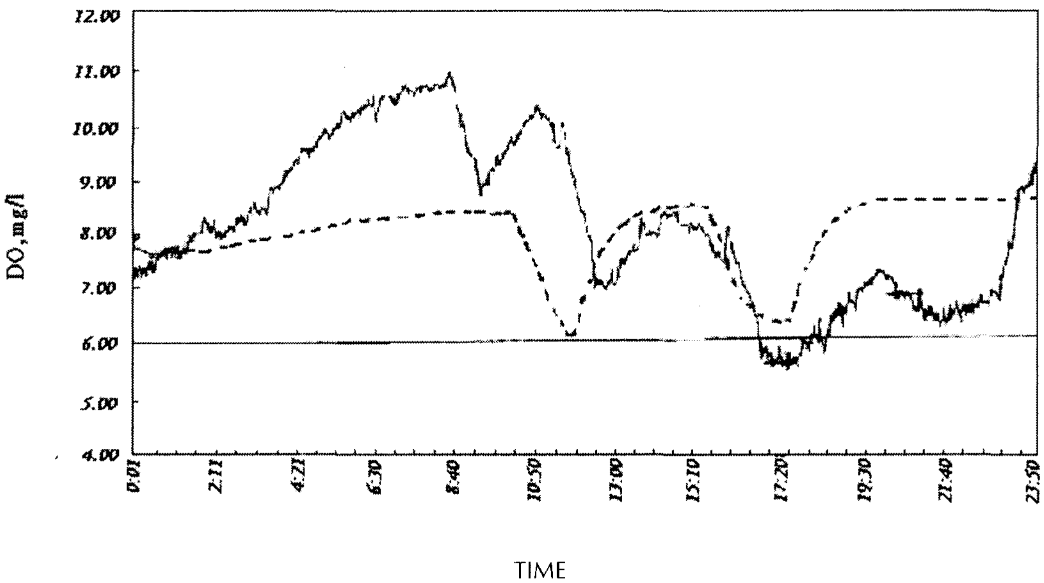

Fig. 6. Fluctuation of dissolved oxygen of indoor (———; Chan(4)) and outdoor systems (-------; present study) within one day.

II. Advantages of using the modified paddle wheel aerator as main oxygenation device.

1. Paddlewheel aerator supplies plentiful oxygen:

Ahmad and Boyd tested standard oxygen transfer rate and standard aeration efficiencies of different paddle shape and depth and diameter(6). The commercial aerators had high values for standard aeration efficiency (2.7-2.9 kg O_2 Kwh^{-1} or 4.05-4.35 kg O_2 HP). However, standard oxygen transfer rate of a commercial 1 HP 6-paddle aerator can reach 4.69 kg O_2/hr, and the electricity cost which generate this amount of oxygen is about 5 % of the cost of pure oxygen. According to Degani et al.(7) an allometric equation for relationship between oxygen consumption (M) and body weight (W) of European eel, *Anguilla anguilla,* at 27 ℃ was Ln M =Ln (0.56) +0.69*Ln (W), i.e. eels of body weight between 10-500g, that is suitable for stocking in this system, will have oxygen consumption of 275-80 mg/Kg/hr.

Suppose the oxygen consumption of a 10 g eel will be 2 times in a stressed condition, i. e. 275*2 or 550 mg/Kg/hr. Theoretically, a 1HP 6-paddle aerator can provide about 75,000 kg (4.05 kg/550 mg.kg) of eels to breathe. Hence, an 1 HP aerator can support a standard 5*5*1 m^3 tank with stocking density of 300 kg/m^3. However, the present study experienced frequent triggering of emergensy oxygenation when the stocking density was greater than 70 kg/m^3, which is about 25% of the theoretical value. It is supposed that other organism, mainly microorganism consumed about 75% of the oxygen, although the particles are removed continuously in this system to prevent sedimentation.

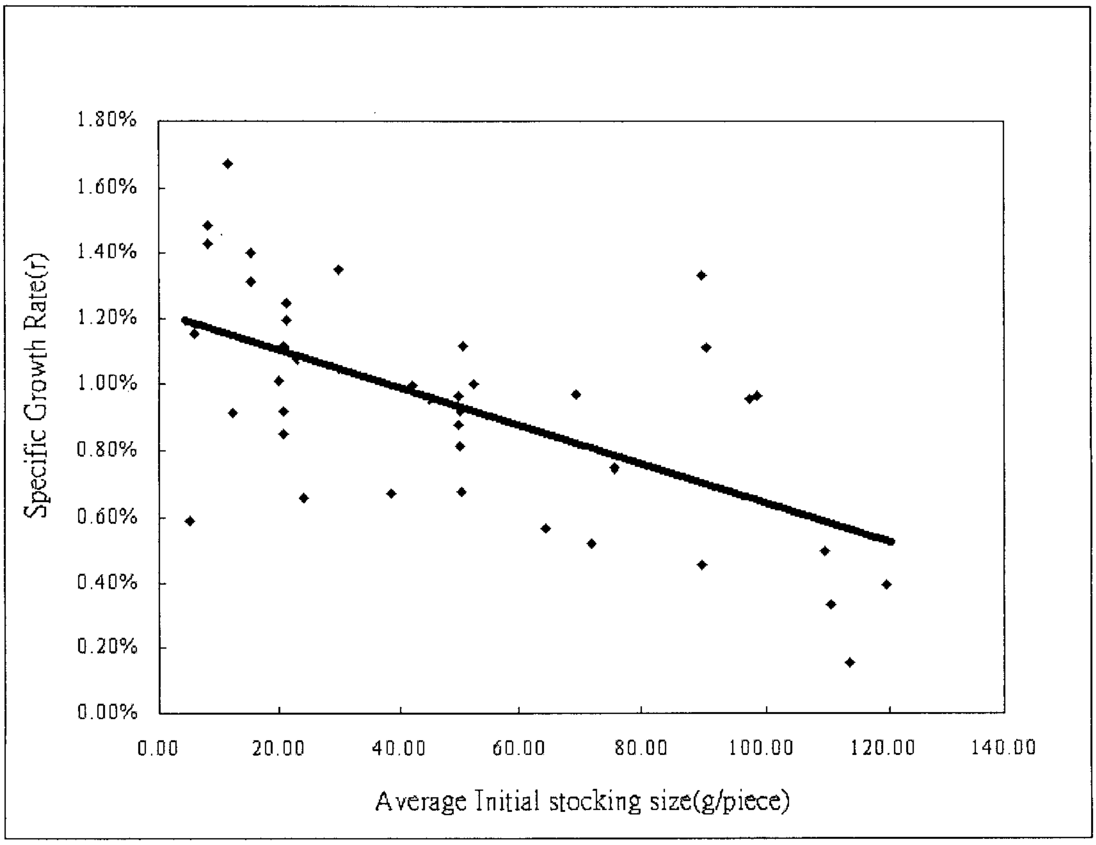

Fig. 7. Relationship of specific growth rate and average initial stocking size of the super-intensive recirculation systems of private farms in Taiwan. (Data from Shyu and Chou[8])

2. Spray of aerator improves gas exchange and stabilizes DO level of culture water: Colt suggested that gas bubble trauma (GBT) can be divided into two types depending primarily on the level of supersaturation[9]. At high levels of gas supersaturation, acute GBT is associated with formation of bubbles in the vascular systems and tissues and high mortality. At low levels of gas supersaturation, chronic GBT is associated with extravascular formation of bubbles in the gut, buccal cavity, hyperinflation of swimbladder, and mortality rates of 1-5 % over extended time periods. Depending on the gas levels and variation with time, both types of GBT may be produced at a given site. The practice of indoor super-intensive recirculating eel culture system sometimes encountered mass mortality due to acute GBT. The oxygen supersaturation with DO level 50 % over saturation is common, especially during high water temperatures in summer time. The chronic GBT, not

well studied, is also most likely to occur. From Fig. 6 it can be concluded that paddlewheel aerator has had better control of DO level owing to its degassing and recovering functions.

III. Comparison of the surrounding and water environments of indoor and outdoor systems.

1. Surrounding environment:

Indoor system was well sheltered by the greenhouse, but it is humid, especially in summertime in the subtropical and tropical area like Taiwan. Mosquitoes and mice are common in the greenhouse. The mosquito larvae are harmful to the biofilter(1) while mice consume fish feeds and may spread diseases. The limited space also hindered the handling of the fish and feeds. Outdoor system was less sheltered. Natural illumination and ventilation save electric power.

2. Water environment:

In the indoor system, the culture water is clearer and it relies highly on pure oxygen for Do supply. Use of paddle wheel aerator is possible, but will increase humidity and noise in the greenhouse. Also, the average water temperature of indoor system (15-32.5 ℃) is about 3 ℃ higher than that of the outdoor system (12.5-29.5 °C), which is advantageous in winter time, but disadvantageous in summer. On the other hand, in the outdoor system, the water is less clear owing to the growth of microalgae and greater water movement by paddle wheel aerator which generate more suspension solids. However, improving water movement and cooling down the water temperature, if not losing to much heat, is good for health, growth and flesh quality of cultured eels. Also, the growth of microalgae in waters of outdoor system seems to stabilize the pH value and kept NH_4^+, NO_2^- in lower level than indoor system.

Conclusion

From the results and discussions presented above, it can be concluded that the performance of the outdoor system in terms of eel production was as good as the indoor system. The capital cost of outdoor system is much lower than that of indoor system, roughly about two-thirds of the indoor system in Taiwan, while the variable cost is about 10 % lower than that of the indoor system. It is prospected that lowering the initial stocking size and expanding the system scale can further optimize the management and production of the outdoor system. This production module has high potential in becoming one of the most efficient and sustainable land-based aquaculture system in subtropical and tropical region.

Acknowledgements

The authors would like to express their deep gratitude to the colleagues of the Department of Aquaculture of Taiwan Fisheries Research Institute for their hard work in pioneering the rearing experiment of super-intensive eel culture in outdoor environment. The authors also would like to thank King-Car Aquaculture Research and Development Center for providing the experimental site and every necessary assistance. The National Science Council supported this study financially under project NSC 88-2622-B-056-001.

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