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Water flow and metabolism-based inter-relationships in land-based finfish culture: studies at Challenger TAFE's Aquaculture Development Unit

Challenger TAFE's Aquaculture Development Unit (ADU) in Fremantle, in collaboration with McRobert Aquaculture Systems (MAS), BOC and the Department of Fisheries, Western Australia, are investigating aspects of land-based culture for marine finfish. The focus on land-based culture in Western Australia has been due to the lack of suitable seacage sites in this state as well as the many advantages of land-based culture over seacages. The rearing environment in land-based systems can be closely monitored and controlled to increase stocking densities and maximise growth throughout the year. With the ability to treat wastewater prior to discharge and by eliminating escapes of domesticated or non-indigenous species, land-based systems are also more environmentally friendly than seacage operations. Land-based systems can either be coastal pump-ashore operations or theoretically could be inland, utilising saline groundwater. Land-based systems are operated as either flow-through or recirculating systems, or a combination of both.

This article outlines the results of some preliminary trials recently completed with yellowtail kingfish and pink snapper in which the rates of oxygen consumption and outflow levels of ammonia and carbon dioxide were determined under different flow rates.

As the cost of pumping water makes up a considerable proportion of the operating cost of a land-based aquaculture operation it is essential that the water be used efficiently and the maximum biomass be cultured in the available water. In land-based systems, water flow is used to flush both solid wastes and metabolites (ammonia and carbon dioxide) from the tanks and to provide oxygen to the fish.

High flow rates are often set primarily to flush solid wastes from the culture tank, which is usually an inefficient use

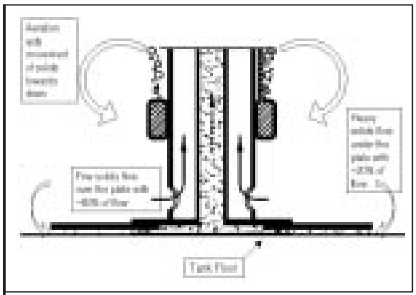

Figure 1a: MAS double drain

of water. With good tank design and hydrodynamics, solids can be removed quickly and efficiently with minimal water volume. In the MAS tanks used in the current experiments, solids are quickly removed from the tanks using a combination of appropriate water hydrodynamics, a MAS double-drain (Figure 1) and a swirl separator. Such efficient solids removal prevents the breakdown of faeces and uneaten food and the subsequent loss of valuable oxygen. In the trials described below, excellent solids removal was achieved at the lowest flow rate investigated ie. 0.56 exchanges per hour.

Oxygen is usually the first factor to limit production in intensive land-based systems. For operations using force-fed air (such as from blowers) to meet the fishes' needs for oxygen, stocking densities are limited by the efficiency of the aeration devices and by the volume of air-saturated water that can be passed through the tanks. Typically, the upper limit for stocking density in such systems is 30–40 kg/m^3. By using pure oxygen to overcome this limiting factor, stocking densities in excess of 200 kg/m^3 can be achieved, thus significantly improving economic returns.

Most oxygen dissolution systems dissolve pure oxygen directly into the main water flow. In such systems, only a limited amount of oxygen gas can be dissolved into each volume of water. Therefore, if more oxygen is needed then the water flow rate must again be turned up. If this increase in water flow is not required for any other purpose, this may again be an inefficient use of water. In the current experiments, BOC 'Turbolox' dissolvers (Figure 2) were employed to provide pure oxygen to the MAS tanks. The advantage of this technology is that it allows the oxygen demand to be met independent of the main flow. Pure oxygen is completely dissolved in a small volume of water that is then rapidly dispersed into the main flow. This 'decoupling' of the water flow from the supply of oxygen can permit less pumping — the exact amount depending then on that required to flush the tank of waste products such as ammonia, carbon dioxide and faeces. In this situation, the maximum sustainable stocking densities will become limited by either the ammonia or carbon dioxide concentration in the tank or by negative social effects between the fish at high densities (ie not by the oxygen supply).

This technology also has the advantage that dissolved oxygen concentrations can be controlled automatically and independently in each individual tank, thus ensuring the most efficient use of pure oxygen. At the ADU a dissolved oxygen probe in the outflow of each tank constantly measures oxygen concentration. The desired oxygen concentration in the tank is set on a computer (Figure 3). When the reading from the probe drops below this set-point, a PLC opens a solenoid valve that allows oxygen gas to pass into the dissolver and subsequently into the tank. The PLC that runs the system operates on 24 V DC power. If mains power is lost to the computer, the PLC and oxygen probes continue to monitor and control the oxygen concentration. In the event of a power failure, or a mechanical problem with any of the system components, emergency oxygen gas turns on automatically and bubbles through diffusers into the tanks.

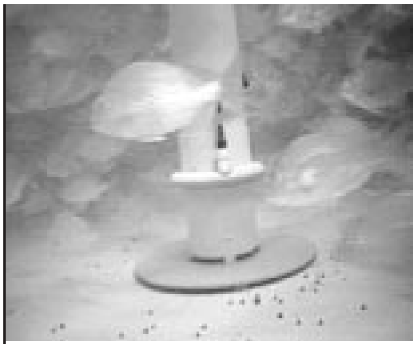

Figure 1b: MAS double drain in snapper tank at the ADU.

As well as making optimum use of pure oxygen, the high level of control that this system offers has proven to be a valuable research tool. With a known flow rate of oxygen to the dissolver and computer-recorded data on how often and for how long the solenoid valve opens, the exact amount of oxygen added to each tank can be calculated. This data, together with the water flow rate, tank volume, fish biomass and the difference in inflow and outflow oxygen concentrations, can be used to calculate the fish's metabolic rate.

Using this system, preliminary trials have recently been conducted at the ADU to calculate metabolic rates of yellowtail kingfish and pink snapper and to investigate the effects of different flow rates on the outflow concentration of ammonia and carbon dioxide. Trials were conducted at water exchange rates of 0.83 exchanges/hour and 0.56 exchanges/hour.

The experiments were conducted in 11m^3 MAS growout tanks at 21°C. Tanks were stocked with 43 kg/m^3 of yellowtail kingfish (average weight 1.4 kg) and 64 kg/m^3 of pink snapper (average weight 780 grams). Each trial was replicated over 2 consecutive days. Fish were fed three times each day and the amount of food eaten was recorded.

Being a fast growing, pelagic fish, yel-

Figure 2 Commercial-scale BOC Turbolox dissolver.

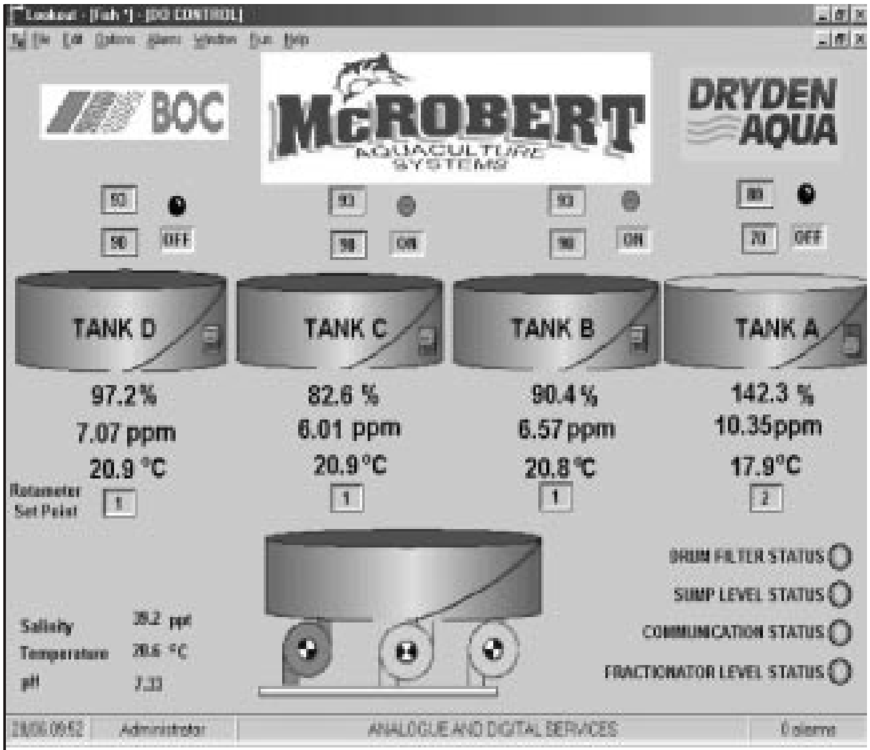

Figure 3 Software package controlling the operation of the MAS recirculating system at the ADU.

lowtail kingfish have a much higher metabolic rate than pink snapper. The average daily metabolic rate (at 21°C) of the 1.4 kg yellowtail kingfish was 209 ± 5 mg O_2/kg biomass/hour, whilst that of the pink snapper was 125 ± 2 mg O_2/kg/hr (Table 1). Using the computer generated data it is also possible to see how the metabolic rate changes over time. As Figure 4 shows, the metabolic rate is low early in the day, before feeding and increases throughout the day as feeding and activity increases. The peak metabolic rate for both species occurred in the early evening; for the yellowtail kingfish the peak was 240 ± 7 mg O_2/kg/hr and for the snapper was 149 ± 3 mg O_2/kg/hr. Interestingly, the metabolic rate of the snapper declined quite rapidly once night set in, whereas that of the yellowtail kingfish remained quite high.

As expected, the oxygen consumption rates were independent of the water exchange rate. At a higher exchange rate, however, more oxygen is supplied with the incoming water and less pure oxygen is therefore required to meet the demands of the fish. For example, at the high water exchange 1.36 ± 0.08 kg of pure oxygen was required per day to maintain the outflow concentration in the yellowtail kingfish tank at 70–72%. At the lower exchange rate this figure was increased to 1.93 ± 0.09 kg. Therefore, the cost savings associated with pumping less water need to be considered against the subsequent increased cost of providing oxygen.

With the ability to maintain oxygen concentrations independent of flow rates, stocking density will be limited by either carbon dioxide or ammonia and these two parameters were also investigated in the current trials. The concentration of carbon dioxide in water is directly related to pH. During the experimental period, pH was therefore logged every 20 minutes in the inflow and outflow of each tank using a WinLab pH probe. From this data, the concentration of carbon dioxide was calculated using an equation developed by Dr Fran Stevens for the ADU water source. The results of the trial are summarised in Table 1. At the low flow rate the difference between the inflow and outflow CO_2 in the yellowtail kingfish tank peaked at 16.4 ± 0.8 mg/L and averaged 13.8 ± 0.1 mg/L over the 24-hour period. With a higher flow rate through the tanks carbon dioxide is flushed out more quickly and the peak and 24-hour average values under a high flow rate were therefore less at 8.39 ± 0.28 mg/L and 7.68 ± 0.05 mg/L, respectively. The concentration of carbon dioxide in the snapper outflow was similar to the yellowtail kingfish. Under the low flow rate the peak and 24 hour-average concentrations for the snapper were 15.1 ± 0.5 mg/L and 13.5 ± 0.2 mg/L, respectively and under the higher flow rates were 8.31 ± 0.01 mg/L and 6.92 ± 0.06 mg/L, respectively. Similar concentrations of CO_2 were measured in the outflow between the two species because of the higher stocking density in the snapper tank. By express-

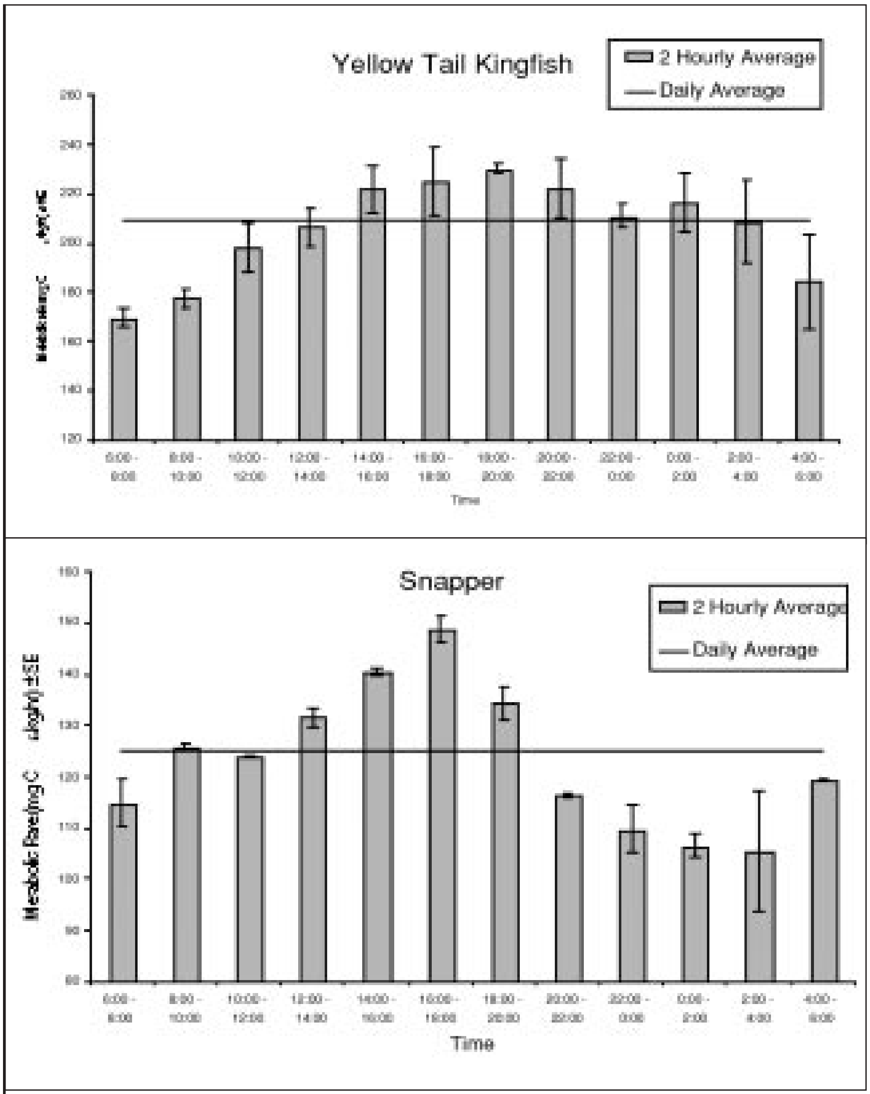

Figure 4 Metabolic rate of yellowtail kingfish (a) and snapper (b).

ing the carbon dioxide as an excretion rate, in a similar way to that described above for oxygen consumption, it can be seen that the rate of carbon dioxide excretion was less for snapper (Table 1). Yellowtail produced an average of 201 ± 1 mg CO_2/kg/hr, whereas the snapper, with a lower metabolic rate produced carbon dioxide at the rate of 122 ± 2 mg/kg/hr. Although there is no information available on the effect of CO_2 on the growth of yellowtail or snapper, anecdotal information for yellowtail kingfish, however, suggests that appetite is depressed at a CO_2 concentration of 25 mg/L. Although this level was not reached in any of the tanks during these experiments it was found that both the snapper and yellowtail kingfish ate less food at the lower flow rate (Table 1). At this point it is unclear whether this reduction in appetite was the result of increased CO_2, slower water movement in the tank or some other factor. This is, however, a very important point and one that the ADU will be investigating further. No aeration or surface agitation was provided in the tanks during the experiments. As carbon dioxide is very soluble, its concentration can be effectively reduced within the tank by aerating the water or providing surface agitation. The figures provided here should therefore represent a worst-case scenario for this set of conditions and lower levels could be expected if aeration or surface agitation were provided.

During the trial, ammonia was also measured at 2 hourly intervals in both the inflow and outflow water of each tank (Table 1). In the high flow experiment, total ammonia in the yellowtail kingfish tank peaked at 0.92 ± 0.06 mg/L and averaged 0.66 ± 0.06 mg/L over the 24-hour period. Total ammonia in the snapper tank was much lower, peaking at 0.46 ± 0.01 mg/L and averaging 0.32 ± 0.01 mg/L. As expected, total ammonia was higher in the low flow experiments. In the yellowtail tanks total ammonia peaked at 1.49 ± 0.30 mg/L and averaged 1.10 ± 0.12 mg/L, whereas in the snapper tanks, the peak concentration was 0.88 ± 0.04 mg/L and the average 0.67 ± 0.04 mg/L. The higher rate of excretion from the yellowtail kingfish was expected, due to their higher metabolism and the fact that they consumed much greater quantities of food during the experiment, compared with the snapper (Table 1).

The extent to which the total ammonia concentration is toxic to the fish

	Yellowtail Kingfish		**Snapper**	
	High Flow	**Low Flow**	**High Flow**	**Low Flow**
Food consumption (g/day)	5960 ± 762	5538 ± 1070	3096 ± 526	2030 ± 542
O_2 consumption (peak) (mg O_2/kg/hr)	240 ± 7		149 ± 3	
O_2 consumption (average) (mg O_2/kg/hr)	209 ± 5		125 ± 2	
ΔCO_2 (peak) (mg/L)	8.39 ± 0.28	16.4 ± 0.8	8.31 ± 0.01	15.1 ± 0.5
ΔCO_2 (average) (mg/L)	7.68 ± 0.05	13.8 ± 0.1	6.92 ± 0.06	13.5 ± 0.2
CO_2 excretion (average) (mg CO_2/kg/hr)	201 ± 1		122 ± 2	
pH average	7.20	7.04	7.24	7.04
pH max	7.27	7.11	7.31	7.11
pH min	7.16	6.85	7.17	6.96
Temperature (average) (°C)	19.7	20.3	19.7	20.3
TAN (peak) (mg/L)	0.92 ± 0.06	1.49 ± 0.30	0.46 ± 0.01	0.88 ± 0.04
TAN (average) (mg/L)	0.66 ± 0.06	1.10 + 0.12	0.32 ± 0.02	0.67 ± 0.04
NH_3-N (peak) mg/L (mg/L)	0.0043 ± 0.0002	0.0051 ± 0.0008	0.0023 ± 0.00002	0.0028 ± 0.000008
NH_3-N(average) (mg/L)	0.0031 ± 0.0002	0.0043 ± 0.0003	0.0017 ± 0.00009	0.0024 ± 0.00007

depends on the pH, temperature and salinity of the culture water. Under the conditions in the current trials, the peak and average unionised (toxic) ammonia levels for yellowtail in the high flow rate trial were 0.0043 and 0.0031 mg/L, respectively and for the snapper were 0.0023 and 0.0017 mg/L, respectively. Values in the low flow rate trial were higher: 0.0051 and 0.0043 mg/L, respectively for the yellowtail kingfish and 0.0028 and 0.0024 mg/L, respectively for the snapper. All of these values are well below the safe levels reported in the literature, suggesting that ammonia should not limit growth for either species at these stocking densities and flow rates.

The species being cultured, their size and the system in which they're being cultured will be the major factors determining the maximum sustainable stocking densities that can be achieved. The species, their size and the temperature of the culture water are important, as it is these factors that determine the rate of oxygen consumption and rates of excretion. For example, the differences in metabolic rate between species were clearly demonstrated in this experiment. Because yellowtail kingfish have a higher metabolism than snapper, they eat more food, consume more oxygen and excrete more ammonia and carbon dioxide. As a result, they will require more oxygen and a greater flow to remove metabolites compared with the same biomass of snapper. As fish grow their metabolism decreases. Therefore, the amount of oxygen and flow a tank will require will depend on the size of the fish that are in it. For example, a tank containing 50 kg/m^3 of small yellowtail kingfish will require more oxygen and flow than a tank of large fish at the same density. Temperature is an important factor; as temperature increases so too does metabolism. Trials are continuing at the ADU to quantify the rates of oxygen consumption and ammonia and carbon dioxide excretion for different sized yellowtail kingfish and snapper at different temperatures. This complete data set will help industry determine the maximum stocking densities and required flow rates for the two species throughout the entire growout period and will also aid in sizing system components such as oxygen dissolution systems, biofilters and degassing systems.

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