RECIRCULATING AQUACULTURE SYSTEMS - A REVIEW

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Contents

Summary

Worldwide aquaculture is an expanding industry and it is suggested that it will, in the future becomes more and more important for the supply of seafood due to decreasing wild capture fisheries. It is proposed that this increase will come from intensifying current production to gain a more efficient outcome. However future aquaculture growth is being challenged by the governmental push for more sustainable and environmentally responsible production. Recirculating aquaculture systems are attempting to satisfy these challenges through minimizing waste output and increasing the recycling of resources. This review will outline the principles and filtration techniques used in current recirculating aquaculture with the inclusion of bacterial processes for nitrification and denitrification. Also examined is current research on the techniques utilised to remove nitrogen species from culture systems. This will hopefully assist in realizing the ultimate aims of 100% recirculating designs and zero emissions. It was concluded from this review that the measure of biological filtration efficiency was at times inaccurate and only applicable for the particular environment examined. The information gained from filter experiments was often difficult to compare to others as there were so many varying factors that were not standardized, which affected the removal rates of the main waste constituents from recirculating aquaculture and render the direct comparison impossible.

1. Current State of Aquaculture and Environment

Aquaculture is currently one of the fastest growing food producing sectors in the world. Current worldwide production is estimated at approximately 47 million tonnes per annum with an increase of 25% between 2000 and 2005. World wild capture fisheries have decreased by 2% over the same period with total production, including both capture fisheries and aquaculture, remaining steady at approximately 141 million tonnes per year (Figure 1). With the world population increasing at a rate of 2% per annum and worldwide demand projected to increase at least by 2% annually, there will be an eventual, if not already, demand shortfall in seafood production.

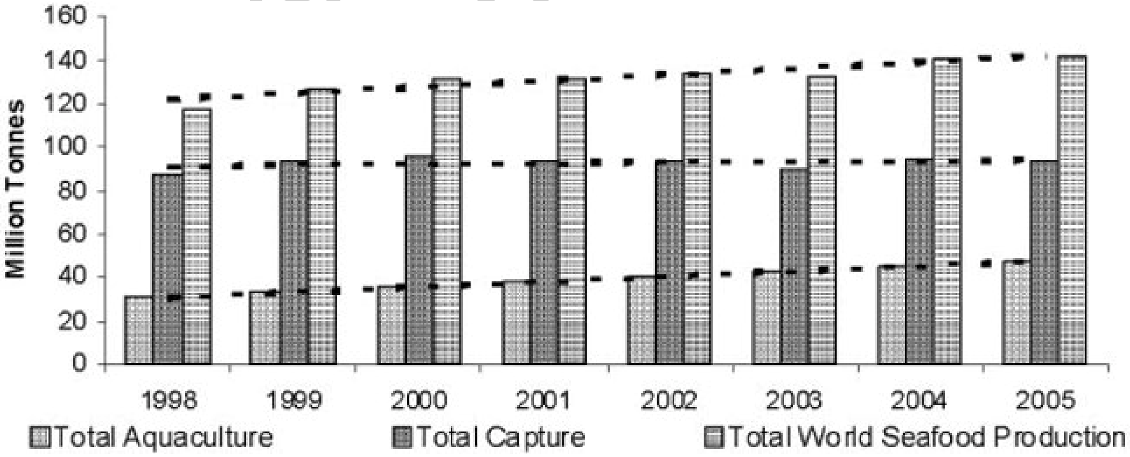

Figure 1. Current world seafood production (Adapted from FAO, 2006).

Taking Australia as an example, the volume of aquaculture production has increased by 80% over the last decade while wild capture increased by only 7%. As a proportion of total volume differentiated by wild caught and aquaculture fisheries, aquaculture has increased from 10% to 16% over the last decade while overall value has increased by

13%. In 2003 –2004 aquaculture accounted for a production value of A$ 700,000,000 and a volume of 43,000 tonnes. This steady but comparatively fast rise in production has prompted state and federal governments of Australia to place more emphasis on aquaculture and encourage the sustainable and rapid development of the industry. This includes primary industry development and increased awareness relating to health standards and environmental guidelines pertaining to the aquaculture industry both land and sea based.

Emphasis has been placed on the environmental issues associated with aquaculture and future expansion. More importantly the question that needs to be considered is what effect will long-term aquaculture have on the surrounding environment as a whole? Sustainable developmental practices, rising production costs and strict legislative guidelines on resource use have constantly influenced the growth of the aquaculture industry. This development has required the industry to change from an extensive and semi-intensive culture to a more intensified and controlled production. This could, as done in the past, lead to a reduced use of resources and an increase in social and environmental problems. The introduction of guidelines and regulations on waste discharge as a result of aquaculture operations has prompted the rapid increase in efficient and technologically innovative products that can help maintain sustainable production.

2. Aquaculture Water Constituents

All waste pertaining to aquaculture is one of the main concerns restricting future growth and sustainability of the industry around the world. Waste discharge is a volatile mixture of nutrients and solids that may adversely alter the surrounding ecological environment. The main constituents of concern from aquaculture include pH, biological oxygen demand (BOD), total suspended solids (TSS), turbidity and nitrogen and phosphorus species.

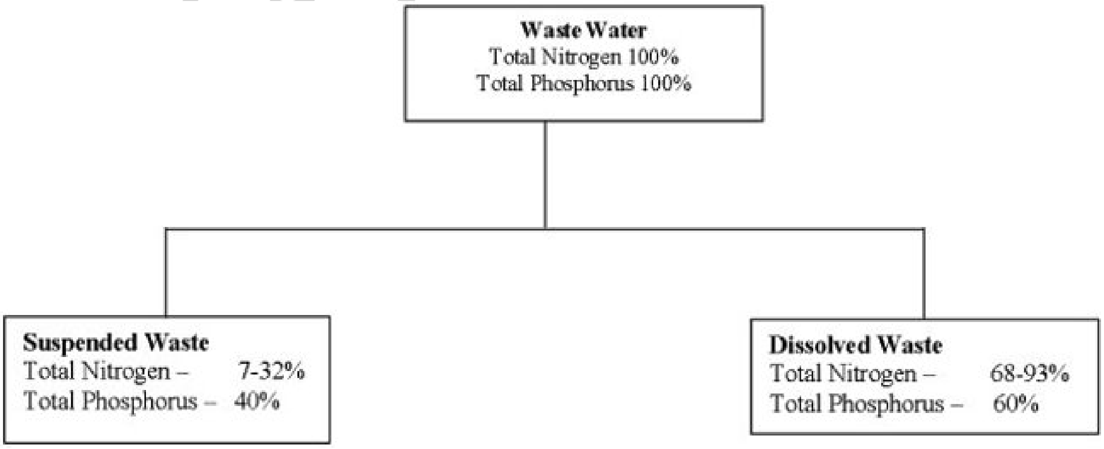

Figure 2 A schematic diagram of the important constituents of waste commonly discharged from aquaculture.

The volatility of wastewater is generally evaluated by the distinction between particulate and dissolved components (Figure 2). Within the dissolved component there are two types of elements that define the specific volatility of wastewater – Total Nitrogen (TN) and Total Phosphorus (TP). TN and TP both exist in solution in different amounts according to the cultured organism, feed conversion ratios and production rates. While a 40/60% split between the solid and dissolved phase of TP respectively is generally observed, 7-32% of TN is commonly in the solid state.

There are two problems caused by the discharge of aquaculture effluent. Firstly the total suspended solids cause an increase in the biological oxygen demand of the water and sediment. This is primarily due to the degradation of organic matter via bacterial processes. This ultimately leads to rapid anoxic conditions within the sediment and increased dissolved nutrients. In the short-term waterways receiving this nutrient rich input can only assimilate so much before its biological carrying capacity is exceeded and the natural state of the environment is distorted. Subsequently there is a complete breakdown of floral and faunal ecological structures that lead to the long-term degradation of the waterway.

The second problem is caused by the dissolved nutrients such as nitrogen and phosphorus. The discharge of these nutrients into receiving waterways affect benthic fauna, macroalgal growth and diversity, epiphyte abundance, and phytoplankton, zooplankton, and bacterial communities. This is often through the direct encouragement of eutrophication and subsequent algal growth.

In important marine coral reef ecosystems, such as the Great Barrier Reef Marine Park in Australia damage can be caused by:

- Algal growth shading the corals from sunlight that is essential for their growth.
- Excessive phosphorus weakening the coral skeleton and making the skeleton more susceptible to storm damage.

Algal growth depends on the availability of organic carbon, nitrogen and phosphorus in the marine ecosystem. However its more likely one of the above nutrients becomes a critical nutrient to trigger or limit algal blooms and it is unlikely that all three nutrients become limiting simultaneously. Therefore, in a given case normally only one nutrient would be critical. While phosphorus is usually the limiting nutrient in freshwater, nitrogen can at times be the limiting nutrient in seawater. Although discharging both nitrogen and phosphorus to oceans (and other inland water courses) will increase algal growth, preventing the discharge of nitrogen rather than phosphorus will be an important step towards preventing the initial bloom in a ocean.

3. Waste Water Discharge Guidelines for Aquaculture

The issue of aquaculture wastewater discharging into the external environment is such that guidelines managing this are set and regulated by state authorities. For example, the aquaculture industry in Australia guidelines are commonly grouped together with other related industries such as the other primary industry agriculture. Due to this the guidelines in Table 1 are relevant for any wastewater that is released into receiving waterways in a given area.

The problems arising with intensification do vary between aquaculture operations in temperate and tropical climates. Discharges from temperate climate operations would amount to less waste than for the same operation in a tropical climate. This was directly related to the metabolism of a species in cold and warm temperatures and the accompanying food conversion ratio (FCR). Based on this, a hypothetical table depicting effluent concentrations from currently utilized production methods (Table 2).

	WA[1]	**NSW[2]**		**QLD[3]**		**SA[4]**		**VIC[5]**	
	Fresh and Saline	**Fresh**	**Saline**	**Fresh**	**Saline**	**Fresh**	**Saline**	**Fresh**	**Saline**
pH	5-9	6.5-8.5		6.5-9	6.5-9	6.5-9	6.5-9	6.4-8.3	
Suspended Solids (mg/l)/ Turbidity (NTU)	<80	<90	13	40-75	40-75	20/ 20	10 / 10	4/ <30	< 75
Biochemical Oxygen Demand (5 day) (mg/l)	<20	<20				10	10		
Ammonia (mg/l)	<1		0.015			0.5	0.2		0.011
Nitrate (mg/l)	<10					<10	<10		
Total Nitrogen (mg/l)		0.2	0.11	<3	<3			0.9	0.12
Total Phosphorus (mg/l)	<1	<1	0.014	0.4	0.4	0.5	0.5	<0.045	0.025

1 – Western Australia; 2 – New South Wales; 3 – Queensland; 4 – South Australia; 5 - Victoria

Note: These guidelines are a brief overview of water quality legislations and do vary between different aquaculture operations depending on discharge rates and areas within specific states.

Table 1. Water quality guidelines relevant to aquaculture for five states within Australia.

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System Type	**Water Use**		**Calculated Effluent Concentration[b]**		
	kg fish/year /(l/min)[c]	**l/kg fish[d]**	**mg N/l[e]**	**mg P/l[f]**	**mg TSS/l[g]**

Cold Water Fish					
Single Pass	1.4	375,000	0.2	0.02	1.3
Serial Reuse	6	88,000	0.7	0.08	5.7
Partial Reuse	50	10,500	5.7	0.67	48
Fully Recirculating	160	3,300	18	2.1	152
Warm Water Fish					
Serial Reuse	16	33,000	2.4	0.8	42
Ponds	294	1,800	44	15	780
Recirculating through wetlands	145	3,600	22	7.8	390
Fully Recirculating	5,000	105	760	27	13,000
[a] The total constituent production is used regardless of whether it is in solid or dissolved form [b] Effluent concentrations calculated as: (Constituent production, (kg constituent)/(kg feed) x (Feed conversion ratio, (kg feed)/(kg/fish))/(water use, (l/kg fish)) x (10^6 (mg constituent)/(kg constituent)). Feed conversion ratios are 1.0 and 2.0 for cold and warm water fish respectively.					
[c] After Chen *et al. (2002).*					
[d] Calculated assuming 365-day year.					
[e] N Production. For cold water fish: 0.06kg N/kg feed, assuming a 50% protein feed and 30% N retention as fish biomass. For Warm water fish: 0.04kg N/kg feed, assuming a 35% protein feed and 30% N retention as fish biomass.					
[f] P production. For cold water fish: 0.007 kg P/kg feed, assuming a 1% P feed and 30% P retention as fish biomass. For warm water fish: 0.014 kg P/kg feed, assuming a 2% P feed and 30% P retention as fish biomass.					
[g] TSS production. For cold water fish: 0.5kg Tss/kg feed (Chen *et al.*, 1997). For warm water fish: 0.7 kg TSS/kg feed (Chen et al., 1997).					

Table 2. Hypothetical effluent concentrations for different types of culture systems assuming that no treatment takes place within the systems and the constituents are uniformly distributed in the effluent.

It is clear that effluent water quality from the different systems decreases as intensification and water recycling increases. This is indicative of the less water being utilized per kilogram of fish produced. When Table 1 is compared and analysed alongside Table 2 an apparent problem arises. As the culture design intensifies the prospects of being within the discharge guidelines for any state become reduced. The calculated effluent concentrations in Table 2 indicate that in cold water systems partial reuse and fully recirculating operations would have difficulty complying with Environmental Protection Agency (EPA) regulations while all warm water systems hypothetically exceed all state water quality guidelines.

However the common assumption that intensification can lead to greater pollution is not always true for aquaculture. In fact a concentrated waste is easier and more efficient to treat than high volume waste. Therefore a system that can concentrate and further utilise this waste is advantages in all regards. Recirculating Aquaculture Systems (RAS) can accomplish this issue possibly reducing the problem of waste discharge, substantially increasing efficiency and economic benefit from any byproducts.

4. Introduction to Recirculating Aquaculture Systems (RAS)

Increasing production costs and stricter environmental regulations have led to the production requirements of an efficient and closely managed system. RAS are beginning to become a popular and well-accepted technique for the culture and sustainable management of aquatic animals. Intensifying the culture of animals encourages the increased production of biomass while reducing the amount of resources required. Subsequently this often leads to a greater accountability for all utilised resources. A professional recirculating aquaculture operation can frequently alleviate problems that have previously hindered expansion.

Traditionally designed RAS involved the application of several filtration stages to refine wastewater and reuse in the same system. The most common combinations involved primary clarification (mechanical), biological and sterilization stages (Figure 3). The mechanical stage typically removes the solid waste while the biological filtration removes the dissolved wastes. Sterilization subsequently reduces the bacterial and pathogen concentration in the entire system. More recently the inclusion of a denitrification stage has shown potential in increasing the volume of water recycled and decreasing waste outputs.

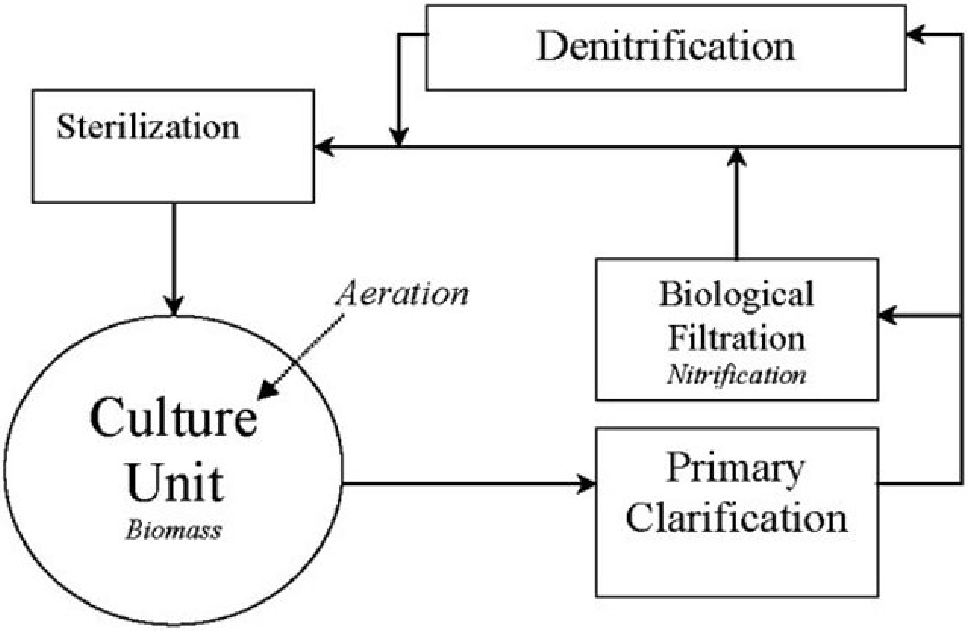

Figure 3. Schematic flow diagram indicating the different categories and stages of filtration commonly found in recirculating aquaculture systems.

Subsequently the intensification of aquaculture and the push for more sustainable production has led to more efficient designs and the utilization of less space, energy and water. RAS have this advantage of being able to produce higher yields while still utilizing small amounts of space, being close to markets and minimizing wastes. In recent years, recirculating aquaculture systems have become a more realistic and feasible option for seafood producers in light of current market demands and industry trends. Therefore the optimization of filtration designs and combinations of filter components is of current interest.

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